

OPTIMIZATION MODEL FOR THE IMPLEMENTATION OF GREEN BUSINESS IN VOCATIONAL EDUCATION TEACHING FACTORIES

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ABSTRACT

The implementation of *green business* principles in vocational education has become a strategic necessity in response to increasing industrial demands for sustainable business practices. Teaching Factory, as a production-based learning model, has significant potential to integrate sustainability values and practices; however, its implementation in vocational education remains suboptimal and largely fragmented. This study aims to analyze the implementation of *green business* in Teaching Factory activities and to develop an optimization model for vocational education. This research adopts an applied research approach using qualitative methods with 20 informants. Data were collected through in-depth interviews, observations, and document analysis at the Teaching Factory units of Manado State Polytechnic, involving managers, instructors, students, and industry partners as informants. Qualitative data analysis was conducted through data reduction, data display, and conclusion drawing. The findings indicate that *green business* practices have been initiated within Teaching Factory activities, yet they have not been systematically integrated into institutional policies, curricula, or standard operating procedures. Institutional policies, human resource competencies, infrastructure, and industry partnerships were identified as key factors influencing optimization. This study proposes an optimization model for *green business* implementation in Teaching Factory that integrates input, process, output, and outcome components to support sustainable vocational learning.

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INTRODUCTION

Environmental sustainability has become a central concern in the development of the global economy and contemporary business practices. The concept of green business has emerged in response to increasing environmental pressures, the depletion of natural resources, as well as regulatory and market demands for environmentally responsible business practices. Green business emphasizes not only environmental compliance, but also operational efficiency, waste management, and the creation of long-term sustainable economic value. Consequently, mastery of competencies related

to green business practices has become a strategic requirement for human resources entering the industrial and entrepreneurial sectors (Saputro, 2024).

Vocational education plays a crucial role in preparing a job-ready workforce aligned with industry needs. This mission is heavily reinforced nationally by Presidential Regulation (Perpres) Number 68 of 2022 concerning the Revitalization of Vocational Education and Training, which mandates systematic alignment between vocational graduates and dynamic workforce demands and strengthen with Regulation on Sustainable Vocational Education (2023). One learning model widely implemented in vocational education is the Teaching Factory (TeFa), a production-based learning approach that replicates real industrial work processes. This model has been proven effective in enhancing technical competencies, work-related skills, and graduates' readiness for employment (Pahmi et al., 2023). Through Teaching Factory activities, students not only acquire theoretical knowledge but also gain direct experience in production processes, management, and entrepreneurship.

However, the implementation of Teaching Factory in many vocational education institutions remains predominantly oriented toward achieving technical competencies and production targets. The integration of green business principles into Teaching Factory activities is often not conducted in a systematic and structured manner. Several studies indicate that environmental sustainability aspects—such as energy efficiency, production waste management, and the use of environmentally friendly materials have not yet become primary indicators in Teaching Factory implementation (Al Hakim & Oktarina, 2024).

This condition reflects a gap between the potential of Teaching Factory as an applied learning platform and the evolving needs of industries that increasingly emphasize sustainable business practices. Studies on green skills and Green Technical and Vocational Education and Training (Green TVET) (Majumdar, S. (2021) reveal that vocational education graduates still face limitations in practical experience related to the application of sustainability principles in real work environments (Putra et al., 2025). This gap may reduce the relevance of vocational graduates to current industry demands, which require not only technical competence but also environmental awareness.

Moreover, the absence of a standardized implementation model has resulted in the partial application of green business principles in Teaching Factory activities, often relying on individual initiatives or internal institutional policies. Applied research in

vocational education emphasizes the need for a comprehensive model that integrates curriculum design, Teaching Factory management, instructor capacity development, industry partnerships, and sustainability-based monitoring and evaluation systems (Saputro, 2024; Iskandar et al., 2024).

Based on these considerations, there is a need for an optimization model for the implementation of green business in vocational education Teaching Factories that systematically integrates sustainability principles into learning and production processes. Such a model is expected to serve as a practical guideline for vocational education managers and educators in optimizing the function of Teaching Factory not only as a means of enhancing technical competence, but also as a platform for developing sustainable business awareness and skills. In this way, vocational education can make a tangible contribution to producing competent, adaptive, and competitive graduates in the era of the green economy.

LITERATURE REVIEW

Concept and Principles of Green Business

Green business refers to a business approach that integrates economic objectives with environmental responsibility through resource efficiency, waste reduction, and the adoption of environmentally friendly practices throughout the value chain. In the management context, green business is regarded as a long-term strategy that is not solely profit-oriented but also emphasizes sustainability based on the triple bottom line principle (people, planet, profit). Studies in management journals indicate that the implementation of green business principles can enhance operational efficiency while simultaneously strengthening organizational competitiveness (Raharjo & Wijayanti, 2022).

From an educational perspective, green business should not be understood merely at a conceptual level, but must be translated into contextual and applied learning practices. Vocational education occupies a strategic position because its learning process is oriented toward real-world work practices, allowing the internalization of green business values through simulations and direct experiential learning. Previous studies emphasize that practice-based learning integrated with sustainability values is more effective in shaping environmentally responsible attitudes and behaviors compared to purely theoretical instruction (Prasetyo et al., 2023).

Teaching Factory as a Vocational Education Learning Model

Teaching Factory (TeFa) is a learning model that adopts industrial systems and work culture within the vocational education environment. TeFa integrates learning activities with the production of goods or services that possess economic value, thereby enabling students to gain authentic work experience during the learning process. Empirical research demonstrates that Teaching Factory significantly contributes to the improvement of technical competencies, soft skills, and the job readiness of vocational graduates (Wibowo et al., 2022).

Furthermore, Teaching Factory also functions as a medium for entrepreneurial and managerial learning. Nevertheless, several evaluative studies reveal that the implementation of Teaching Factory still encounters challenges related to management, process standardization, and program sustainability. The primary focus of implementation is often limited to achieving production outputs and fulfilling curricular requirements, while environmental and sustainability dimensions have not yet been optimally integrated (Suryanto & Nugroho, 2023).

International Perspectives and Comparative Optimization Models

To address these limitations, international models offer valuable frameworks for comparative analysis:

Germany's Dual Training System, embeds green technology modules into traditional apprenticeships, ensuring that resource management and renewable energy competencies are core requirements across manufacturing trades rather than isolated electives (World of TVET, 2024).

ASEAN Regional Frameworks, guided by the ASEAN TVET Council (ATC) Work Plan, regional initiatives spearheaded by bodies emphasizes the institutionalization of green human capital and specialized green skill taxonomies across member states (The ASEAN Magazine, 2026).

Despite these international precedents, existing optimization frameworks often suffer from structural flaws. Many models rely heavily on top-down administrative compliance rather than bottom-up pedagogical integration. Furthermore, prior frameworks frequently treat environmental indicators as separate monitoring metrics rather than embedding them directly into daily instructional instruments, such as job sheets and operational work instructions.

Integration of Green Business in Teaching Factory

The integration of green business into Teaching Factory represents a strategic

approach to addressing the demands of sustainable industries. Through this integration, Teaching Factory serves not only as a means of enhancing technical competence but also as a learning laboratory for environmentally responsible business practices. Previous research indicates that incorporating environmental aspects into production-based learning can increase students' awareness of energy efficiency and waste management (Handayani et al., 2023).

However, such integration continues to face various challenges. Several studies report that the absence of a structured implementation model has resulted in sporadic and unsustainable applications of green business principles within Teaching Factory activities. The lack of sustainability indicators, environmentally oriented standard operating procedures, and limited instructor competencies are identified as major inhibiting factors (Kurniawan & Lestari, 2024). Therefore, an optimization model is required to systematically integrate green business principles into all components of Teaching Factory implementation.

Optimization Model Implementation in the Context of Vocational Education

An optimization model in vocational education is understood as a systematic effort to enhance the effectiveness of program implementation through improvements in planning, execution, and evaluation. In the context of Teaching Factory, optimization encompasses the strengthening of management practices, human resource development, the provision of adequate infrastructure, and the reinforcement of industry partnerships. Other studies emphasize that an optimal vocational learning model must exhibit a clear structure, well-defined performance indicators, and sustainable evaluation mechanisms (Yuliani et al., 2022).

The development of an optimization model for implementing green business within Teaching Factory is therefore essential to bridge the gap between sustainability theory and vocational learning practice. This model is expected to serve as an applied guideline for vocational education institutions in managing Teaching Factory activities that are oriented toward environmental sustainability and the needs of green industries.

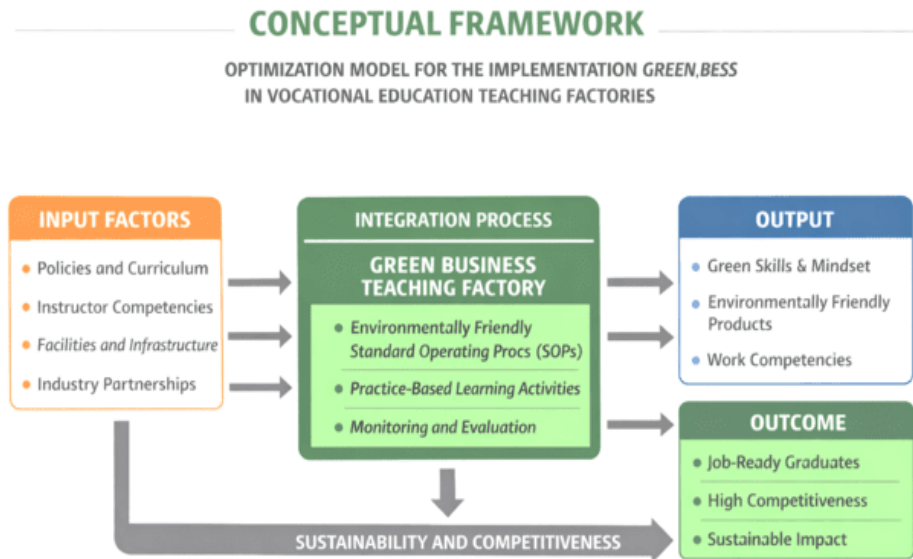


Figure 1. Conceptual Framework

METHODS

Type and Research Approach

This study adopts an applied research approach using qualitative research methods. The applied research approach is employed because the study aims to develop an optimization model for the implementation of green business in vocational education Teaching Factories that is practical and implementable. The qualitative method is used to obtain an in-depth understanding of practices, dynamics, and challenges related to the implementation of green business within Teaching Factory activities.

Research Ethics

This study received ethical approval from the Research Ethics Committee of Politeknik Negeri Manado. All informants provided written informed consent prior to participation, ensuring they were fully informed about the study's purposes, procedures, potential benefits, and voluntary nature. Informant identities are strictly protected through the use of alphanumeric codes and pseudonyms in all research reports and publications. Furthermore, all collected data are stored in encrypted, password protected digital storage accessible only by the research team and are utilized exclusively for academic research purposes.

Research Informants

The research was conducted at Politeknik Negeri Manado, particularly within the Teaching Factory units that implement production-based learning. The research objects include Teaching Factory management, learning and production processes, and the implementation of green business principles in Teaching Factory activities. Research

informants were selected using purposive sampling, considering their direct involvement in Teaching Factory activities. The informants consisted of:

Informant Category	Number
Teaching Factory Managers	1
Lecturers/ Instructors	9
Students	5
Industry Partners	5

The selection of informants aimed to obtain comprehensive data from multiple stakeholder perspectives.

Data Analysis

Data were collected using the following techniques:

1. In-depth interviews with key informants to explore their understanding, experiences, and perspectives regarding the implementation of green business in Teaching Factory activities.
2. Direct observation of learning activities and production processes in the Teaching Factory to identify the application of environmentally friendly practices.
3. Document analysis, including curricula, standard operating procedures (SOPs), Teaching Factory activity reports, and cooperation agreements with industry partners.

Data analysis was conducted qualitatively through the following stages:

1. Data reduction, involving the selection and categorization of data according to the research focus.
2. Data display, presented in the form of descriptive narratives and thematic matrices.
3. Conclusion drawing, by identifying patterns and key themes related to the optimization of green business implementation in Teaching Factories.

The results of the analysis served as the basis for formulating an optimization model for green business implementation tailored to the context of Politeknik Negeri Manado.

Data Trustworthiness

To Ensure data trustworthiness and qualitative rigor, this study employed established validation strategies

1. Triangulation, cross verifying information using data source (interviews, observation) and methods to confirm consistency
2. Member Checking, returning transcribed interviews and preliminary thematic findings to key informants to verify the accuracy and authentic representation of their perspectives

3. Peer Debriefing, engaging in discussion with fellow researcher and academic peers to review analytical processes, challenge assumptions, and minimize researcher bias
4. Audit Trail, maintaining a comprehensive, systematic log of all research steps, raw data, coding decisions, and analytical memos to document the entire research process transparently

Research Procedure

The research procedure comprised the following stages:

1. Preliminary study and literature review on green business and Teaching Factory
2. Field data collection at Politeknik Negeri Manado
3. Qualitative data analysis and identification of optimization factors
4. Development of the optimization model for green business implementation in Teaching Factory activities
5. Model validation through limited discussions with internal stakeholders.

RESULT AND DISCUSSION

This study investigated the implementation of *green business* principles in vocational education Teaching Factories at Politeknik Negeri Manado and developed an optimization model based on an applied qualitative research approach. The findings reveal that *green business* practices have been initiated within Teaching Factory activities; however, their implementation remains partial and has not yet been systematically integrated into institutional policies, curricula, or standard operating procedures.

The study identified four key factors influencing the optimization of *green business* implementation: (1) policies and curricula, (2) human resource competencies, (3) facilities and infrastructure, and (4) industry partnerships. The absence of formal sustainability-oriented policies and standardized implementation frameworks has resulted in practices that rely heavily on individual initiatives rather than institutional systems.

Practice-based learning (*learning by doing*) within Teaching Factories demonstrates strong potential for internalizing sustainability values, as students gain direct experience with resource efficiency, energy use, and waste management. Nevertheless, the lack of standardized monitoring and evaluation mechanisms limits systematic feedback and continuous improvement. In terms of outputs, the implementation of *green business* contributes to the development of students' *green skills* and *green mindset*, alongside improvements in technical and managerial competencies. At the outcome level, the

findings indicate positive implications for graduates' job readiness and competitiveness in sustainable industries. Based on these findings, the study proposes an optimization model integrating input, process, output, and outcome components to support the systematic and sustainable implementation of *green business* in vocational education Teaching Factories.

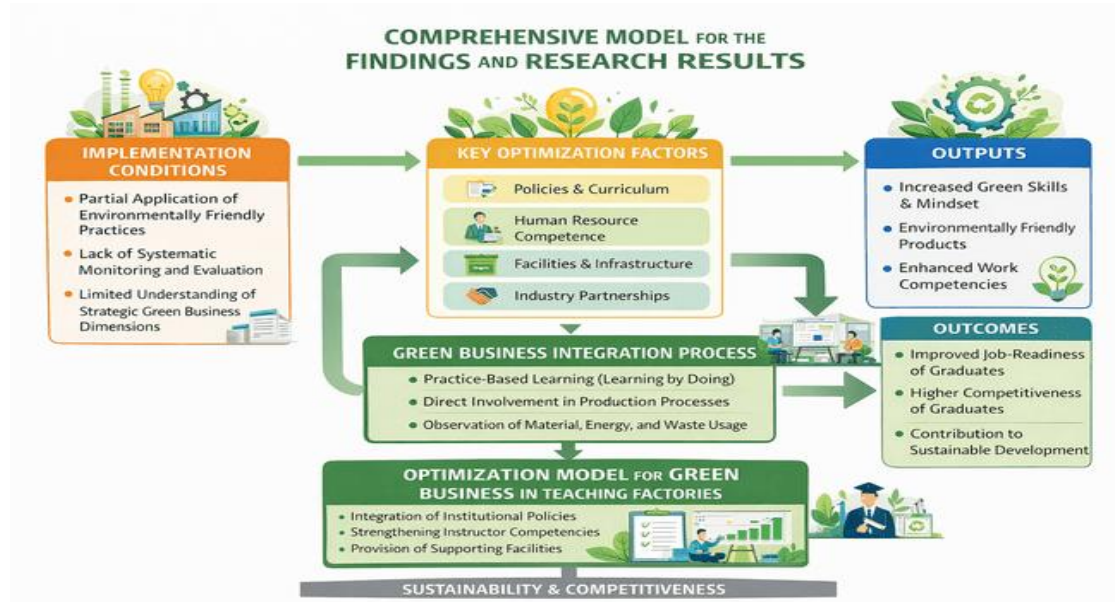


Figure 2. Comprehensive Model

Condition of Green Business Implementation in Teaching Factories

The findings indicate that the implementation of green business principles in Teaching Factory activities at Politeknik Negeri Manado has been initiated; however, it remains at an early and partial stage. Several environmentally friendly practices have been applied, including efforts to reduce production waste, more efficient use of raw materials, and the maintenance of workplace cleanliness. Nevertheless, these practices have not yet been systematically integrated into institutional policies, curricula, or standard operating procedures governing Teaching Factory activities.

This operational reality was highlighted by a TeFa Manager, who noted:

“we do practice good housekeeping and try not to waste materials during practical sessions, but we mostly do it out of general habit or budget constraints rather than following a strict green manufacturing standard. There is no official green module guiding our daily workshop workflow yet.” (M01, TeFa Manager)

Field findings further reveal varying levels of understanding among managers and instructors regarding the concept of green business. Some informants perceive green business merely as cleanliness and material efficiency, while strategic dimensions such as energy efficiency, supply chain sustainability, and long-term economic value have not

been fully comprehended. This limitation directly restricts comprehensive pedagogical transfer.

An instructor further elaborated on this gap during the interviews:

“when we talk about green business, honestly, our minds immediately go to cleaning up the lab. Concepts like carbon footprints reduction, energy auditing, or circular supply chains feel a bit too abstract because our technical training background focused purely on production output and machinery operation.” (IL03, Instructor)

This condition has contributed to the suboptimal internalization of green business values within the Teaching Factory learning process, reinforcing the urgent need for structured optimization framework that bridges basic environmental housekeeping with modern, strategic green industry competencies.

Factors Influencing the Optimization of Implementation

Based on interviews, observations, and document analysis, the study identified several key factors influencing the optimization of green business implementation in Teaching Factories:

Policies and Curriculum

The Teaching Factory curriculum does not explicitly incorporate learning indicators related to environmental sustainability. The absence of specific institutional policies addressing green business has resulted in implementation largely depending on individual instructor initiatives.

“our semester learning plans are strictly tailored to standard competency modules required by the national curriculum. Because there is no formal policy mandating green performance indicators, integrating sustainability topics depends entirely on whether an individual lecturer chooses to insert them into their lectures.” (IL02, Lecturer)

Human Resource Competence

Instructors' competencies in applying environmentally friendly production practices require enhancement through continuous training and mentoring. Instructors tend to prioritize the achievement of students' technical competencies rather than integrating sustainability aspects into the learning process.

“our primary pressure during TeFa sessions is making sure students successfully operate and finish the production target within the allotted timeframe. Teaching them about eco design specialized training that most of us have never formally received.” (IL05, Lecturer)

Facilities and Infrastructure

The availability of supporting facilities for green business practices—such as standardized waste management systems and energy-efficient equipment—remains limited. This condition restricts the optimal implementation of environmentally friendly practices.

“we want to manage production waste properly, but our workshop lacks dedicated segregation bins, recycling channels, or energy monitoring meters. We end up disposing through conventional waste streams simply due to infrastructure limitation.” (IL07, Laboratory Lecture)

Industry Partnerships

Collaboration with industry partners is predominantly oriented toward fulfilling production needs and work-based learning requirements, rather than specifically supporting the development of green business practices. This orientation affects the transfer of knowledge and experience related to sustainable industrial practices to students.

“most of our current industry partners collaborate with us strictly on commercial orders, product specifications, and delivery deadlines. They rarely discuss or share their internal green manufacturing protocols with out students during internships or joint production projects.” (IL04, Lecturer Industry Relations)

Green Business Integration Process in Teaching Factories

The integration of green business principles within Teaching Factories occurs through practice-based learning (learning by doing), where students are directly involved in production activities. Observational data indicate that these activities have significant potential as a medium for internalizing sustainability values, as students can directly observe and experience the impacts of material usage, energy consumption, and waste management.

This practical learning dynamic was emphasized by an instructor observing student engagement in the workshop:

“when students actually have to handle the leftover raw materials and clear out the workshop floor themselves, it creates a much stronger impression on them than just reading a textbook about waste management. They start realizing how much material is wasted when a cut is imprecise.” (IL08, Instructor)

Furthermore, students themselves recognize how practical engagement bridges the

gap between theory and environmental responsibility. A student participating in the Teaching Factory noted:

“working directly on commercial orders in the TeFa makes us realize that businesses care about speed and costs, but when we throw away usable off-cuts, we actually see the environmental cost right in front of us. It makes us think twice about how we use resources.” (ST04, Student)

However, monitoring and evaluation of environmentally friendly practices have not been conducted in a structured manner. There are no standardized indicators used to assess the success of green business implementation, either in terms of learning processes or production outcomes. Consequently, the integration process lacks systematic feedback necessary for continuous improvement.

This structural evaluation gap was further explained by a program coordinator:

“we evaluate student based on whether their final product meets technical specifications and whether the project was finished on time. We do not have a grading rubric or a checklist that scores them on energy conversations, material efficiency, or eco friendly handling during the production process.” IL09, Coordinator Lecturer)

Output of Green Business Implementation in Teaching Factories

The findings demonstrate that the implementation of green business principles in Teaching Factories has generated several positive outputs, although these outcomes have not yet reached an optimal level. Students actively involved in Teaching Factory activities exhibit increased awareness of the importance of material efficiency and environmentally responsible workplace management. In addition, students begin to demonstrate a sense of responsibility toward cleanliness and sustainability in production processes.

This emerging shift in student mindset was highlighted by an instructor supervising workshop activities:

“even though our green modules are still informal, you can see a noticeable change in how students treat materials by the end of their TeFa rotation. They stop treating leftover as absolute trash and start thinking about how they can reuse off-cuts for smaller components or properly sort them for recycling,” (IL01, Supervisor Instructor).

In terms of competence development, students not only experience improvements in technical skills but also begin to develop a green mindset, as reflected in how they plan and carry out production activities. Students themselves expressed a growing

appreciation for combining technical proficiency with resource mindfulness. A student participant noted:

"Working in the Teaching Factory taught us that being a good technician isn't just about making things work or meeting the client's deadline; it also matters how much waste we generate and how cleanly we manage our workspace. It changes our perspective on what professional standards look like." (S05, Student Participant)

The products generated through Teaching Factory activities also show potential to be developed into environmentally friendly products, although they are not yet supported by standardized sustainability criteria. A program evaluator further commented on this output:

"The tangible prototypes and commercial items our students produce have great market potential. If we can back these outputs up with verified green metrics and certified eco-friendly processes, our graduates will step into the industry with a distinct, competitive edge." (IL08, Evaluator Lecturer)

Outcomes and Formulation of the Optimization Model

Based on the overall research findings, it can be concluded that the implementation of green business principles in Teaching Factories has a positive impact on the job readiness and competitiveness of vocational education students. Nevertheless, to achieve more significant and sustainable impacts, a structured and contextual optimization model for green business implementation is required.

The optimization model formulated in this study emphasizes the integration of institutional policies, the strengthening of instructor competencies, the provision of supporting facilities, and the development of sustainability-oriented industry partnerships. This model is expected to serve as an applied guideline for Teaching Factory managers in optimizing production-based learning that is aligned with green business principles and the needs of sustainable industries.

Implementation of Green Business in Vocational Education Teaching Factories

The research findings indicate that the implementation of green business within Teaching Factories at Politeknik Negeri Manado remains partial and has not yet been systemically integrated. This finding is consistent with studies in vocational education suggesting that sustainability practices are often not positioned as a core component of production-based learning systems, but rather as supplementary activities (Slamet & Widodo, 2022). Such conditions indicate that green business has not been fully

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recognized as a long-term learning strategy within Teaching Factory implementation.

Conceptually, green business requires a paradigm shift from a purely production-oriented focus toward resource efficiency and process sustainability. However, this study reveals that institutional policies and Teaching Factory standard operating procedures have not explicitly incorporated sustainability indicators. This finding reinforces the argument that the successful integration of green business is strongly influenced by policy commitment and governance structures within vocational education institutions (Hidayat & Mulyani, 2023).

Determining Factors in Optimizing Green Business Implementation

Policy frameworks, human resources, facilities and infrastructure, and industry partnerships were found to play a significant role in determining the level of optimization in green business implementation. The absence of formal policies regulating sustainability integration has caused Teaching Factory practices to rely heavily on individual instructor initiatives. This finding aligns with vocational education management research emphasizing that instructional innovation is difficult to sustain without strong structural support and institutional policy frameworks (Rohman & Sari, 2022).

From a human resource perspective, instructors serve as key facilitators in practice-based learning environments. Nevertheless, limited training related to green practices has resulted in instructors prioritizing technical aspects over sustainability dimensions. This finding supports previous research highlighting the importance of developing vocational educators' competencies to facilitate the transition toward sustainable education models (Lestari et al., 2023).

Teaching Factory Learning Processes and the Internalization of Sustainability Values

Practice-based learning (learning by doing) in Teaching Factories demonstrates substantial potential as a medium for internalizing green business values. Through direct involvement in production processes, students can concretely understand the implications of material use, energy consumption, and waste management. However, the findings of this study indicate that such learning processes are not yet supported by standardized monitoring and evaluation systems. This condition is consistent with the findings of Prabowo and Nugraha (2023), who argue that practice-based learning without clear sustainability indicators risks losing its reflective and evaluative orientation.

From a vocational pedagogy perspective, continuous evaluation is a critical element in ensuring meaningful learning experiences. Therefore, the absence of green business evaluation instruments within Teaching Factories may hinder the systematic and measurable development of a green mindset among students.

Outputs, Outcomes, and Implications for Model Development

The research outputs indicate that students have begun to develop awareness of the importance of resource efficiency and environmentally responsible work practices. This finding supports the view that direct experience in sustainable production environments can foster pro-environmental attitudes and behaviors among vocational learners (Susanto & Kurniawan, 2022). However, in the absence of a structured implementation model, such impacts tend to remain individual in nature and are difficult to institutionalize or replicate.

At the outcome level, the implementation of green business within Teaching Factories has the potential to enhance graduates' job readiness and competitiveness. This is consistent with studies indicating that mastery of green skills is a key determinant in improving the relevance of vocational graduates to future industry demands (Yuniarti et al., 2023). Accordingly, the development of an optimization model for green business implementation represents a strategic step in strengthening the role of Teaching Factories in supporting sustainable vocational education.

Despite the clear theoretical and operational benefits of integrating green business into Teaching Factories, transitioning toward this optimized model will inevitably encounter deep-seated structural and cultural barriers in practice:

1. **Political and Bureaucratic Inertia**, public higher vocational education institutions often operate under rigid bureaucratic hierarchies and central key performance indicators (KPIs) tied primarily to graduation rates, job placement speeds, and short-term revenue generation from commercial TeFa orders. Introducing sustainability metrics that do not carry immediate weight in national accreditation scores can lead institutional leadership to deprioritize green reforms in favor of traditional output targets.
2. **Organizational Culture and Resistance to Change**, changing established workshop habits requires overcoming a deeply entrenched production-first culture among veteran instructors and workshop managers. Practices such as material over-consumption or convenient waste disposal methods are often normalized. Shifting toward rigorous life-

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cycle thinking and energy auditing can be met with institutional friction if perceived as administrative burdens rather than core pedagogical enhancements.

3. Resource and Budgetary Trade-offs, green retrofitting—such as installing energy-smart meters, eco-friendly material alternatives, or professional waste segregation systems—requires upfront capital expenditure. In resource-constrained public polytechnics, competing budgetary priorities often mean sustainability upgrades take a back seat to basic equipment maintenance.

Proposed Optimization Model

To overcome these structural, cultural, and operational barriers, the proposed Optimization Model for Green Business Implementation in Teaching Factories (Billet, 2020) operates as a multi-dimensional framework spanning five core pillars:

1. Institutional Policy and Governance Integration. The model mandates the formal codification of green business principles into the polytechnic's strategic plan and standard operating procedures (SOPs) and UNESCO-UNEVOC (2022). By aligning Teaching Factory KPIs with national policies (such as Presidential Regulation No. 68 of 2022 on Vocational Revitalization), sustainability compliance transitions from an optional individual choice into a binding institutional standard.
2. Curriculum Harmonization and Green Pedagogical Design. Rather than introducing separate, isolated environmental classes, the model embeds green learning outcomes directly into Semester Learning Plans and practical job sheets. Competencies such as material efficiency, lean manufacturing, and waste reduction are treated as core technical grading criteria.
3. Human Resource Capacity Building. A structured upskilling pipeline for instructors and workshop supervisors is established, moving beyond basic theoretical seminars into hands-on industrial green certifications, energy auditing workshops, and collaborative faculty training programs with certified sustainable industry partners.
4. Eco-Infrastructure and Sustainable Workshop Management. The model provides guidelines for transforming physical workshop spaces—introducing standardized waste management segregation channels, energy monitoring dashboards, and material optimization protocols that simulate modern eco-industrial standards.
5. Sustainability-Oriented Industry Partnerships. The framework reorients industry collaborations away from purely transactional, commercial order fulfillment toward green technology transfer. Industry partners are engaged to co-develop green project-based

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learning modules, mentor students on circular economy practices, and evaluate student portfolios based on environmental performance.

CONCLUSION

Based on the research findings and discussion, it can be concluded that the implementation of green business within vocational education Teaching Factories at Politeknik Negeri Manado has been initiated; however, it remains partial and has not yet been systematically integrated. Environmentally friendly practices are largely dependent on individual initiatives and are not sufficiently supported by institutional policies, curricula, or sustainability-oriented standard operating procedures. This study identifies several key factors influencing the optimization of green business implementation in Teaching Factories, namely policies and curricula, human resource competencies, the availability of facilities and infrastructure, and industry partnerships. The absence of a structured implementation model has limited the potential of Teaching Factories as platforms for sustainable learning.

Through an applied qualitative research approach, this study develops an optimization model for green business implementation that integrates input, process, output, and outcome components. The model positions the Teaching Factory not only as a means of enhancing technical competencies, but also as a strategic instrument for fostering a green mindset, developing green skills, and improving the competitiveness of vocational education graduates.

To transition this optimization model from theory to institutional reality, the following explicit recommendations are offered: For Vocational Education Leadership & Management. Formally embed sustainability metrics and green performance indicators into institutional strategic plans and daily Teaching Factory operational guidelines. Transition away from ad-hoc green activities by updating Semester Learning Plans (RPS) to mandate environmental tracking as part of student grading rubrics. For Instructors & Workshop Supervisors. Participate proactively in upskilling programs focusing on lean manufacturing, energy auditing, and waste reduction methodologies. Shift pedagogical practices to explicitly highlight the environmental and economic trade-offs of material consumption during production tasks. For National Policymakers (Ministry of Education and Directorate General of Vocational Education). Issue clear, standardized policy guidelines and funding incentives specifically tied to Green TVET and sustainable Teaching Factory development. Align institutional accreditation criteria with green operational benchmarks to ensure long-term sector-wide compliance.

To ensure a smooth, measured roll-out of the optimization model, institutions are encouraged to follow a phased, four-stage timeline over a 12-to-18-month period: Phase 1: Institutional Audit and Policy Alignment (Months 1–3). Conduct a baseline audit of current workshop facilities, review existing curricula, and draft formal institutional policies and standard operating procedures (SOPs) integrating green business metrics. Phase 2: Human Resource Capacity Building & Partner Engagement (Months 4–6). Conduct intensive instructor upskilling workshops and establish formal agreements with sustainable industry partners to co-develop green project-based learning modules. Phase 3: Pilot Implementation & Formative Evaluation (Months 7–12). Roll out the optimized Teaching Factory model in selected pilot workshops. Utilize member checking, peer debriefing, and formative feedback loops to refine job sheets, waste management protocols, and grading rubrics. Phase 4: Full Institutionalization & Summative Review (Months 13–18+). Scale the model across all campus production units, initiate quantitative or mixed-methods tracking of student competency outcomes, and conduct a comprehensive summative review for broader institutional accreditation.

This study has several limitations that should be acknowledged. First, the research was conducted at a single vocational education institution; therefore, the findings and the proposed model remain contextual and cannot be broadly generalized. Second, the qualitative approach focuses on informants' perceptions and experiences and does not quantitatively measure the impact of green business implementation on Teaching Factory performance or student learning outcomes. Third, the limited research timeframe restricts observation of the long-term implementation of the optimization model.

Based on these limitations, future research may be directed toward the following agendas: Quantitative or mixed-methods testing of the model to measure the effectiveness of green business implementation in Teaching Factories on competency development, job readiness, and graduate competitiveness. Replication studies across diverse vocational education institutions to examine the validity and generalizability of the proposed optimization model. Development of comprehensive sustainability indicators and evaluation instruments to assess green business implementation in production-based learning environments. Longitudinal studies to examine the long-term impacts of green business-oriented Teaching Factory implementation on graduates and vocational education institutions

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