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MORALITY BEFORE KNOWLEDGE

Open innovation analysis of the penta helix electric bus collaboration: Advancements in sustainable energy and engineering

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ABSTRACT

Background: This research aims to analyze the application of the Open Innovation concept in the Penta Helix collaboration on the electric bus project at the Faculty of Engineering, Universitas Indonesia. The Penta Helix model involves five main actors: Academia, Industry, Government, Mass Media, and Society. This research employs a case study approach focusing on the Faculty of Engineering, Universitas Indonesia as the research object. **Method:** Data was collected through in-depth interviews, literature reviews, and document analysis. This approach was used to examine the collaboration's dynamics and the development process of the electric bus technology. **Finding:** The results indicate that the collaboration between the university and industry successfully developed an innovative and sustainable electric bus technology, complying with government standards. Academia plays a role in research and technology development, industry supports with financial resources and market access, government provides regulations and policy support, mass media disseminates information, and society offers feedback and technology adoption. **Conclusion:** The main challenges faced in this collaboration include stakeholder coordination and aligning the objectives of each actor. Additionally, cultural differences and expectations between the university and industry also pose barriers. Nevertheless, this research finds. that effective synergy among the five actors can accelerate innovation and provide significant economic and social benefits. This research is expected to contribute to the development of university-industry collaboration in Indonesia and enrich the literature on Open Innovation. **Novelty/Originality of this Study:** This study offers insights into how the Penta Helix collaboration model can drive innovation in the electric bus sector, highlighting the synergy between academia, industry, government, mass media, and society in the context of Open Innovation in Indonesia.

KEYWORDS: sustainable; development; open innovation; penta helix; university-industry collaboration.

1. Introduction

Currently, most academics focus more on publishing cases of successful open innovation. There are still few studies that discuss the failures of open innovation. Beyond merely celebrating success, we must also consider several fundamental conditions that need to be met for open innovation to succeed. Open innovation also offers several benefits, such as increasing employment opportunities, supporting new businesses, and enhancing national competitive advantage (Osorno-Hinojosa et al., 2022).

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For companies, open innovation is a way to discover new business opportunities, find solutions, and improve internal business practices. According to the Open Innovation Report (2021), the primary reason for pursuing external collaboration is to discover new business opportunities (46%), followed by finding new solutions (45%), and thirdly, improving internal business practices (38%). To ensure the success of open innovation practices, companies need information about the factors required. As many as 89 percent of corporations that manage collaborations through a business unit dedicated to open innovation consistently achieve their business goals. This indicates that significant effort and resources are needed to successfully implement these practices. Clearly, educational institutions and corporations operate in vastly different ways and have very different goals, making it essential for an internal or external facilitator to ensure that such collaborations can be maximized.

Developing high-tech innovation is not easy for a single university and requires collaboration with other universities, the government, and industry due to the high costs of research, development, and testing. Such collaboration enables the pooling of resources and expertise to achieve goals more efficiently. Government and industry support is crucial in providing regulations, funding, access to technology, and assistance in commercializing innovative products. Innovation and technology are vital for national and global economic development, as industrial companies increasingly need knowledge to enhance production and product development. Government programs, from the national to the local level, are essential in strengthening innovation initiatives. Indonesia, as the world's largest nickel spplier, holds significant potential as an EV battery producer. The global commitment to achieve net zero emissions by 2060 is driving the transition to sustainable solutions. The transportation sector in Jakarta is a major contributor to air pollution, exacerbated by the high population of motorcycles. The transition to electric vehicles (EVs) is seen as a solution, with policies supporting the electric vehicle and battery ecosystem. These policies aim to achieve 30% electric vehicle production of the total population by 2030. The increasing sales of electric cars in Indonesia highlight the strong potential for the future of EVs in the country.

Despite having abundant natural and human resources, the development of electric transportation in Indonesia lags behind countries like Singapore, India, and Thailand. The 2023 Global Electric Mobility Readiness Index (GEMRIX) ranks Indonesia 21st out of 35 global markets, indicating that many factors still need improvement, such as macroeconomics, customer readiness, charging infrastructure, government regulations, and market competitiveness (Pasha, 2020). Vehicle manufacturers must quickly adjust their products and supply chains to align with market readiness to face the challenges of industrial transition.

The transition to battery electric vehicles (BEVs) has the potential for a positive economic impact, such as reducing CO_2 emissions by up to 14 million tons per year, cutting fuel imports by 26.1 million barrels per year, and increasing GDP by IDR 3,826 trillion over 30 years. This potential is supported by a young population, urbanization trends, and the existence of 960 battery exchange stations. Although conventional fuel prices remain low, Indonesia's nickel reserves, government incentives, and interest from private investors promise significant growth in the EV sector.

Indonesia must focus on electric transportation innovation, particularly electric buses, to capitalize on opportunities in the uncontested market. With the majority of the population relying on public transportation and two-wheeled vehicles, and the adoption of electric cars still low, electric buses present a more realistic option. Learning from China, which started with the electric motorcycle and bus industries, demonstrates that this strategy is effective for entering the EV market. Furthermore, the growing number of public transportation passengers reveals significant potential to optimize this sector and support Indonesia's commitment to reducing greenhouse gas emissions.

This study aims to understand how Open Innovation practices within the Penta Helix collaboration can accelerate the innovation process and enhance organizational competitiveness in Indonesia, particularly in the electric bus project at the Faculty of

Engineering, University of Indonesia. This research is also important for exploring effective collaboration models, technology transfer, and socio-economic impacts. Through a more in-depth analysis, it is expected that university-industry partnerships can become more effective and sustainable, thereby promoting the development of environmentally friendly technologies in Indonesia.

The study examines the application of the Open Innovation concept within the Penta Helix collaboration in the electric bus project at the Faculty of Engineering, University of Indonesia. The Penta Helix model involves five key actors: Academia, Industry, Government, Mass Media, and Society. This collaboration is expected to drive technological innovation and support economic growth in Indonesia. Currently, open innovation practices have been widely adopted in various developed countries, but in Indonesia, their application remains limited. This research focuses on how Open Innovation practices are applied within the Penta Helix collaboration on the electric bus project at the Faculty of Engineering, University of Indonesia. The main question raised is how the interactions and roles of each actor in the Penta Helix model can contribute to the development of this innovation (Halibas, 2017; Liu et al., 2018). The collaboration between the university and industry is expected to result in innovative and sustainable electric bus technology that aligns with government standards (Polese et al., 2021; Ranga & Etzkowitz, 2013).

The objective of this study is to analyze the roles and reciprocal relationships between the Penta Helix actors, as well as to identify the challenges and benefits of this collaboration. This research employs a case study method, with the Faculty of Engineering, University of Indonesia, as the research object. Data were collected through in-depth interviews, literature reviews, and document analysis. This study aims to contribute academically to the fields of innovation management and business administration while providing practical guidance for universities, industries, governments, and communities in developing environmentally friendly technologies like electric buses.

This research is framed by theories related to open innovation by Chesbrough et al. (2013) and the Penta Helix model. The Penta Helix theory emphasizes five key roles: universities, industry, government, media, and communities (Aquilani et al., 2020). Consequently, the research informants are limited to managers and consumers directly involved in the electric bus collaboration project in the Department of Mechanical Engineering, Faculty of Engineering, University of Indonesia. The study limits its scope to the prototype stage of the electric bus. LPDP, as the government actor, is only considered within the funding aspect.

1.1 Open Innovation and university-industry collaboration (UIC)

Henry Chesbrough introduced the concept of open innovation in 2003. Open innovation allows companies to leverage both internal and external ideas in their innovation development processes. The success of open innovation requires several conditions, such as workforce mobility to enable knowledge exchange between organizations and an internal R&D environment that supports this collaboration. Effective knowledge transfer combines creativity and collaboration, relying on individuals who can connect and integrate knowledge from various sources. These individuals are often referred to as "T-shaped managers," as they possess deep expertise in specific areas while also having the ability to collaborate across different fields.

University-industry collaboration (UIC) refers to the interaction between higher education institutions and industries for knowledge and technology exchange (Jones & Coates, 2020). According to Bekkers et al. (2008) and Oliver (1990), there are six key factors important for inter-organizational relationships: (1) informal personal relationships, (2) formal personal relationships, (3) third parties, (4) formal agreements, (5) informal agreements, and (6) focused structures. The motivational factors for UIC include: (1) the need to remain competitive internationally and adapt to technological changes, (2) stability through collaboration strategies, (3) legitimacy for enhancing reputation, (4) reciprocal expertise in research and employment opportunities, (5) efficiency through enhanced R&D

and simplified funding, and (6) asymmetry for technology commercialization and increased financial gains.

UIC activities encompass: (1) meetings and networking, (2) communication, (3) training, (4) personnel mobility, and (5) job provision. The benefits for both universities and industries include economic, institutional, and social aspects. However, UIC also faces challenges, including mission drift, quality issues, conflicts, and risks. To facilitate effective UIC, capacity and resources, legality and policy, management and organization, as well as consideration of technological, political, and social issues, are essential (Ankrah, 2015).

1.2 Service-dominant logic (SDL)

Service-Dominant Logic (SDL) is an approach that views customers as co-creators of value in the innovation process. This perspective emphasizes the importance of adapting to customer needs and inputs in creating value. SDL represents a fundamental shift in business logic, focusing on the active involvement of customers in shaping products or services (Vargo & Lusch, 2004). The SDL framework consists of five key premises (Vargo & Lusch, 2016): (1) Service as the Basis of Value Exchange: Service is the foundational element of value exchange between businesses and consumers; (2) Customers as Co-Creators of Value: Customers actively participate in creating value through their interactions and feedback; (3) All Social and Economic Actors as Resource Integrators: Every participant in the process, including businesses, consumers, and other stakeholders, integrates resources to co-create value; (4) Value is Determined by the Consumer: The true worth of an innovation is defined by how customers perceive and utilize it; (5) Value Co-Creation is Coordinated through Institutions and Institutional Arrangements: The co-creation process is shaped by societal norms, regulations, and frameworks that facilitate collaboration and innovation.

This framework highlights the interconnected relationship between businesses and intermediaries, where there is an exchange of information, knowledge, and competencies. Companies influence value co-creation by developing innovation capabilities through specific intermediaries (Perano et al., 2018). The SDL theory (Lusch & Vargo, 2014) focuses on the exchange of resources between actors and their contribution to the formation of value co-creation (Spohrer & Maglio, 2009).

1.3 Penta helix

The Penta Helix model is used to create synergy among various stakeholders, with the goal of achieving a common understanding and collaboration in the innovation process. In this study, the Penta Helix model is defined as a collaborative framework involving stakeholders from Academia, Business, Government, Community, and Media (ABGCM) to drive open innovation. Academia, academia contributes to human resource development, such as students, lecturers, and researchers, who play a crucial role in applying knowledge and research into innovations and creating new products/businesses (Carayannis et al., 2012). Academia also facilitates the transfer of research and innovation into practical applications that can benefit society and industry.

Business, business actors or entrepreneurs are expected to contribute to a knowledge-based economy through venture capital and their ability to run businesses. They support innovation with capital, networks, business collaborations, and Corporate Social Responsibility (CSR) initiatives (Carayannis et al., 2012). Business involvement enhances the commercialization of innovations and provides the resources necessary for scaling up ideas into marketable products. Government, the government holds authority over legal and public policies. Key indicators for the government dimension include political and legal aspects such as permits, policies, incentives, and grants for the development of open innovation, as well as the provision of basic infrastructure such as electricity, water, and access roads (Etzkowitz & Leydesdorff, 1997; Fathin, 2016). The government's role is vital in creating a regulatory environment that fosters innovation and supports collaborations among stakeholders.

Community, in this study, the community refers to the general local population, as well as various groups formed around shared interests, such as regional arts councils, non-governmental organizations (NGOs), or hobby-based groups. The community supports innovation by creating forums for interaction and fostering creativity (Awaluddin et al., 2016). Communities generate ideas for innovative product development (Nylander & Tholander, 2017) and serve as platforms for sharing and co-developing innovations (Lindtner et al., 2014). Communities also directly participate in driving innovation and knowledge-based economies through representation or direct engagement.

Media, media plays a critical role in disseminating the information needed by stakeholders. Journalists contribute by covering and informing stakeholders, and educating the public through publications. Media also facilitates feedback and interactions among stakeholders (Effendi et al., 2016), linking key actors to national and global markets, and maintaining corporate reputations at an international level (Awaluddin et al., 2016). Media support indicators include the extent of publications for institutions and their products, obtaining ideas and customer insights, and the intensity of communication between institutions and stakeholders through media channels. The Penta Helix model emphasizes the integration and interaction of these five key actors to foster innovation, drive economic growth, and contribute to societal well-being. By aligning the efforts of academia, business, government, community, and media, the model helps create a more dynamic and sustainable ecosystem for open innovation.

2. Methods

This study employs a qualitative approach to understand social phenomena from the perspectives of those directly involved. The aim of this approach is to explore open innovation practices within the Penta Helix collaboration at the Faculty of Engineering, Universitas Indonesia (UI). This research is exploratory, intending to delve into the topic of open innovation. From a benefits perspective, this is classified as pure research aimed at generating new knowledge about social phenomena. Based on the temporal dimension, this study is a case study focusing on open innovation practices at the Faculty of Engineering, UI. Regarding data collection techniques, this research employs field research. Data are collected through interviews and literature studies. Interviews serve as a primary source for obtaining firsthand information from informants, while literature studies are used as a secondary source to enrich the understanding of the research topic. Qualitative data analysis is conducted using coding techniques to identify, compare, and interpret patterns and themes.

The data collection and analysis processes occur simultaneously or are iterative (Neuman, 2014). Informants are group members who can provide information regarding the researched group. They are selected based on their familiarity with the group's culture, their contributions to the research topic, their willingness to be interviewed, and their objectivity. In this study, the informants are Penta Helix actors involved in the electric bus collaboration at the Faculty of Engineering, UI. The research is conducted at the Faculty of Engineering, Universitas Indonesia, focusing on the electric bus collaboration involving various Penta Helix actors. This study aims to explore how open innovation practices are applied in the Penta Helix collaboration at the Faculty of Engineering, UI, to develop electric buses, analyzing the roles of each actor in the process.

3. Results and Discussion

3.1 Result

The Penta Helix model positions academics as the central players in knowledge and innovation development. In the electric bus development project at the Faculty of Engineering (FT) Universitas Indonesia (UI), academics play a crucial role with several

contributions, including technology and knowledge development, as well as the formation of networks and collaborations. Academics at FT UI are responsible for creating and advancing the underlying technologies for the electric bus project. Since 2012, FT UI has been engaged in electric vehicle technology research, starting with the "Molina" project (National Electric Vehicle) and subsequently transitioning to electric bus development. This collaboration also fosters the development of a more comprehensive system, encompassing everything from electric motor development to control systems and the materials used for the bus body.

This project is a collaboration involving various leading universities in the country. FT UI partners with industries such as PT Mobil Anak Bangsa (MAB) and PT Petrosea to develop the main components of the electric bus. The government, through LPDP (Education Fund Management Institution), supports this project with the Rispro Invitasi funding scheme to ensure that the innovations have significant economic and social impacts. The results of this project contribute to higher education, research, and the commercialization of electric vehicle technology. One significant outcome of this funding is its contribution to higher education and human resource development. Hundreds of graduates have worked on this electric vehicle research. Many of them participated in this project as part of their theses, dissertations, or final projects. This illustrates that the project contributes not only to technological innovation but also to the formation of a new generation of experts and researchers in the electric vehicle field. Industry actors emphasize that the Ph.D. candidates produced from this project are not merely those who "pass by," but rather those who produce high-quality scientific work. Publications in high-reputation journals serve as one indicator of success.

FT UI establishes cross-disciplinary and institutional networks and collaborations in the electric bus project. Students from various levels and disciplines are involved, enriching the innovation process and knowledge transfer. Collaboration includes other universities such as ITB (Bandung Institute of Technology), UGM (Gadjah Mada University), and ITS (Sepuluh Nopember Institute of Technology), along with partnerships with industries like PT Mobil Anak Bangsa (MAB) and PT Petrosea. This collaboration facilitates knowledge and experience exchange between academics and industry, accelerating technology development. Faculty members involved in this project often continue to collaborate with FT UI, strengthening networks and disseminating knowledge. Knowledge transfer is also supported through internship programs and training for students, opening opportunities for interaction with industry professionals. This project exemplifies how the Penta Helix theory is applied in developing electric vehicle technology through robust collaboration between academia, industry, and government.

FT UI has developed electric buses as part of the UI Green Metric initiative, leveraging local body manufacturing industries. The LPDP (Education Fund Management Institution) supports this project in line with national policies for green technology. Collaboration with Petrosea and PT Mobil Anak Bangsa (MAB) combines academic expertise with industry needs to provide greener and more efficient transportation solutions.

The project fosters the emergence of startups such as PT NSAD, which plays a vital role in developing electric bus technology. This initiative generates innovative products and creates new job opportunities, demonstrating how universities can act as catalysts for innovation. The financial support from LPDP, through the Rispro Invitasi scheme, aids in the development of electric buses, with annual evaluations to ensure performance. Government policies facilitate research and development, supported by various ministries and agencies. This collaboration ensures that research results can be implemented and commercialized effectively.

From the industry perspective, FT UI advances electric bus development with support from LPDP and partnerships with companies like PT Mobil Anak Bangsa and Petrosea. This collaboration integrates academic expertise with industry needs, resulting in technology that promotes green and efficient transportation. FT UI also fosters startups like PT NSAD, which contribute to developing motor control systems. The government, through LPDP, provides funding and policy support for electric bus development. The Rispro Invitasi policy

ensures collaboration with the industry for commercializing research outcomes. Additionally, the government coordinates the downstream efforts of research results through various ministries and agencies.

Media plays a crucial role in simplifying technical information and communicating it to the public. Media coverage helps raise public awareness of green technology and encourages the adoption of electric vehicles. Furthermore, the media facilitates dialogue between the government, academics, and the community. Finally, the community gains education and information about electric vehicle technology through this project. Awareness of the importance of green technology and sustainability increases, promoting the adoption of electric vehicles and supporting environmentally friendly policies.

In summary, the collaborative efforts of academia, industry, government, media, and the community create a robust framework for developing electric bus technology, enhancing knowledge transfer, and promoting green innovations in Indonesia. This model exemplifies the effective application of the Penta Helix framework in addressing contemporary transportation challenges.

The electric bus project at FT UI involves various actors at each stage. Academics lead the development of technology, while industries such as PT Mobil Anak Bangsa and PT Petrosea provide technical support and resources. The government, through LPDP, offers funding and supportive policies. Media plays a role in disseminating information and raising public awareness, while the community participates as users and beneficiaries of the developed technology. This collaboration among stakeholders ensures that each phase of the project proceeds smoothly and achieves the desired objectives.

Table 1. of Level of involvement of each actor in the UI electric bus project

Project Stages	Academics	Industry	Government	Mass media	Public
Research and development	High (Research and technological innovation)	Medium (Identify opportunities)	High (Project funding)	Low (Initial news coverage)	Low (Potential feedback)
Resource Provision	Medium (Technical consulting)	High (Provision of infrastructure and components)	High (Project funding)	Medium (Coverage of developments)	-
Implementation and Testing	High (Technology testing and evaluation)	Medium (Providing trial facilities)	Medium (Regulatory support and monitoring)	Low (Publication of trial results)	Low (Initial use)
Commercialization	Medium (Prototype refinement)	High (Marketing and distribution strategy)	Low (Additional regulations)	Low (Promotion and information dissemination)	Low (Early adoption of technology)
Usage and Feedback	Low (Minimal academic engagement)	Medium (Product performance monitoring)	Low (Policy impact monitoring)	Low (User report)	Low (Prototype feedback)

The electric bus project at UI is supported by several key factors. Collaboration between academia and industry, such as the partnership between FT UI and PT Mobil Anak Bangsa and PT Petrosea, leverages available expertise and resources. Government support through funding from LPDP and favorable policies accelerates technology development. The media also plays an important role in raising public awareness about the significance of environmentally friendly technologies. Community participation as users further supports the implementation of this technology (Buwana & Nusyamsyiah, 2018).

However, this project also faces several challenges. Coordination among stakeholders often proves to be a challenge, as aligning diverse interests and schedules can be complicated. Regulatory barriers, such as complex licensing processes, may slow down project progress. The procurement of specific components for new technologies often presents obstacles. Additionally, although support is available, the resources and funding may sometimes be insufficient to meet the demands of large-scale projects.

3.2 Discussion

The electric bus project at UI applies the concept of open innovation by involving various external and internal actors in the innovation process. Collaboration among academics from FT UI, industries such as PT M.A.B. and PT P., as well as support from the government and the community, illustrates how diverse ideas and resources are combined to create value. This process reflects the open innovation paradigm, which encourages the exchange of knowledge and technology among various stakeholders to advance innovation.

Meanwhile, the Penta Helix Model is implemented in this project by involving five main actors: academia, industry, government, media, and the community. Academics lead the development of technology, industry provides technical support and resources, the government offers funding and supportive policies, media helps disseminate information and raise public awareness, and the community participates as users of the technology. The involvement of these five actors demonstrates the synergy generated through cross-sector collaboration, in line with the Penta Helix theory (Farinha et al., 2014; Guntoro, 2021).

Additionally, the electric bus project at UI is also related to Service-Dominant Logic (SDL), where customers (in this case, the community and public transport users) are considered co-creators in the value creation process (Windsor, 2017). The developed technology focuses on the needs and input from users and how they can actively participate in the use and further development of that technology. SDL emphasizes the importance of interaction and resource exchange among actors to create shared value.

3.2.1 Industrial practices in open innovation in electric bus collaboration penta helix actors' perspective

In the context of the electric bus project at the Faculty of Engineering, Universitas Indonesia (FT UI), identifying innovation potential is a crucial step that guides the development and implementation of new technology. Through interviews with academics, as well as perspectives from the government and industry, this research will analyze how innovation potential is identified and developed. The triangulation of data involves insights from three key stakeholders: academia, government, and industry.

As the initiator of UI Green Metric, a global ranking system for sustainable campuses, UI holds both the responsibility and motivation to develop technologies that support campus sustainability. Transforming conventional campus shuttle buses into electric buses is a strategic move to meet the criteria for environmentally friendly transportation. This initiative reflects UI's commitment to green technology innovation and sustainability, setting a tangible example for other institutions worldwide.

Moreover, FT UI's experience in developing an electric city car prototype over the past two years provides a solid foundation for advancing innovations in electric vehicles. This demonstrates the faculty's technical expertise and capacity to further develop this technology. The "Molina" (Mobil Listrik Nasional) project serves as a stepping stone for future advancements and mapping the potential for establishing a national automotive industry centered on electric vehicle technology.

From the perspective of national industrial potential, Indonesia possesses a strong coachbuilding (karoseri) industry, particularly in bus manufacturing, which presents a significant opportunity to support the development of electric buses using existing infrastructure. FT UI recognizes the potential to leverage local coachbuilding industries to facilitate electric bus production, which is more feasible compared to smaller vehicles like city cars.

The electric bus market primarily consists of transportation service providers, simplifying both marketing and maintenance efforts. For instance, companies such as DAMRI can efficiently manage the maintenance of their electric bus fleets without requiring an extensive network of service workshops, as would be necessary for private passenger vehicles. These factors make electric buses a more practical and economically viable option for mass transportation in Indonesia.

3.2.2 Community practices in open innovation in electric bus collaboration in the perspective of penta helix actors

In the Penta Helix model, the community is recognized as a key actor in supporting the adoption and implementation of innovation. However, in the context of the electric bus project at FT UI, community involvement tends to be more passive, primarily limited to usage and indirect feedback. The community in this case mainly consists of public transportation users, UI's academic community, and local residents who utilize the bus service.

The electric bus innovation being developed by the Faculty of Engineering at Universitas Indonesia (FT UI) in collaboration with industry partners such as PT Mobil Anak Bangsa and Petrosea offers numerous benefits from various perspectives within the Penta Helix model. However, one of the biggest challenges is the lack of community participation in this project. This is primarily due to limited public exposure to information about the advantages of electric buses. In reality, active community involvement is crucial for improving innovation quality through constructive feedback.

From an academic perspective, the electric bus initiative provides a rich research platform for the development of electric vehicle technology. Academics have the opportunity to conduct in-depth and applied research, produce high-impact scientific publications, and advance knowledge and technology in this field. Additionally, the project involves many undergraduate, master's, and doctoral students, not only enriching their academic experience but also preparing graduates with the necessary skills to tackle challenges in the electric vehicle industry.

4. Conclusions

Open innovation, which combines external and internal ideas to drive innovation, has proven to play a significant role in this project. Collaboration among academia, industry, government, mass media, and the community has resulted in a number of relevant and applicable findings, such as electric vehicle (EV) city cars, electric buses, accredited publications, startup incubation, collaborative networks, and more. Academics at FTUI play a crucial role in technology and innovation development, particularly in the electric bus project. They are involved not only in fundamental research but also in developing practical applications and technologies with commercial potential. Their contributions include the development of electric motor control systems and other environmentally friendly technologies.

Industries such as PT Mobil Anak Bangsa, PT Petrosea, PT Pindad, and PT NSAD contribute significantly by providing technical resources and support for the implementation of research results. This collaboration helps accelerate the commercialization process of innovations developed by academics. The government acts as a primary facilitator by providing funding and regulations that support electric bus development. Implemented policies help create a conducive environment for innovation and collaboration between academia and industry. The mass media plays a role in disseminating information and knowledge about the electric bus project to the broader public, helping to raise awareness about the importance of environmentally friendly technologies and innovations. The community, although more passive in this project, provides valuable feedback regarding the use and benefits of electric buses. Their involvement is essential to ensure that the innovations developed meet the needs and expectations of end users.

Overall, this study demonstrates that Penta Helix collaboration at FTUI has successfully created significant and applicable innovations in electric bus development. However, there is still room for improvement and enhancement, particularly in community involvement and the development of business models that support the commercialization of innovations. Through increased cross-sector collaboration and comprehensive impact evaluation, it is hoped that open innovation practices can continue to evolve and provide greater benefits

for all parties involved. This research not only contributes to the understanding of open innovation practices but also offers concrete recommendations for academics, industry, government, mass media, and the community to enhance collaboration and innovation in the future. With sustained support and stronger synergy among Penta Helix actors, the development of environmentally friendly technologies, such as electric buses, can reach its full potential and have a significant positive impact on the environment and the economy.

Based on the research findings, the following recommendations are provided for the Penta Helix actors and future research, academics are encouraged to continue enhancing collaboration with industry and government. Programs that involve researchers from various disciplines and institutions should be strengthened to generate more comprehensive and applicable innovations. Additionally, it is important to establish more incubation programs to support technology startups founded by students and researchers, which can provide guidance, funding, and access to industry networks to accelerate the commercialization of innovations. University curricula should also be continuously adjusted to align with industry needs and the latest technological developments, including the addition of courses focused on innovation, entrepreneurship, and interdisciplinary collaboration. Finally, encouraging applied research that can be directly implemented by industry will enhance the relevance and benefits of research conducted at universities.

Industries are expected to continue supporting research and development at universities by providing the necessary technical, financial resources, and facilities, including sponsorship for research projects and offering internships for students. Furthermore, building closer collaborations with universities through long-term partnership programs, which may include joint research, product development projects, and employee training, will be highly beneficial. Involving universities in the early stages of product development to ensure that the resulting innovations meet market needs and have high commercial potential is also essential.

The government needs to continue supporting collaboration between universities and industry through favorable policies and regulations, including the provision of fiscal incentives, ease of licensing, and funding for innovative projects. Increasing the allocation of funds for research and development, particularly focusing on environmentally friendly and sustainable technologies such as electric buses, is also important. Additionally, providing the necessary infrastructure to support the development of new technologies, including research laboratories, innovation centers, and testing facilities, will be highly beneficial. The government should also initiate educational campaigns and public awareness programs to encourage the adoption of environmentally friendly technologies, including promoting the benefits of electric buses and other green technologies to the wider community.

The media is expected to take a more active role in promoting innovation and environmentally friendly technologies. By raising public awareness, the media can help drive the adoption of new technologies developed through this collaboration. Furthermore, disseminating information about innovative projects and their successes through various media channels will help enhance visibility and public support for these projects. The media can also provide informative educational programs about green technologies and their benefits, including articles, documentaries, and panel discussions with experts. Facilitating feedback from the public regarding the innovations developed is also important, as the media can serve as a bridge between technology developers and the community to ensure that the innovations produced meet the needs and expectations of end users.

The community is expected to be more proactive in providing feedback and supporting the innovations developed. Active participation from the community will help ensure that the innovations align with their needs. Furthermore, encouraging the community to adopt and utilize environmentally friendly technologies such as electric buses will assist in achieving cleaner and more sustainable environmental goals. The public also needs to continuously enhance their knowledge and awareness of the importance of environmentally friendly technologies through educational programs and awareness campaigns. Establishing innovation communities that can collaborate with universities and

industries in developing and implementing new technologies is also crucial, as these communities can serve as platforms for sharing ideas, hosting workshops, and supporting innovative projects.

Future research is recommended to explore the active involvement of the community in innovation projects more deeply, as well as its impact on the successful implementation of technology, including studies on how the community can engage more in the development and adoption of new technologies. Additionally, further analysis of Penta Helix collaboration in other sectors with significant potential for social and economic benefits, such as health, agriculture, and renewable energy, is also essential. Conducting impact evaluations of open innovation collaboration on economic and environmental sustainability, including cost-benefit analyses, environmental impact studies, and long-term economic benefit assessments, will provide more comprehensive insights. Developing innovative business models that can be adopted by universities and industries to accelerate the commercialization process of innovations, including strategies for monetizing research and development results, will support the sustainability of these innovations. Furthermore, researching and developing new technologies that have the potential to enhance the efficiency and effectiveness of open innovation collaboration, such as utilizing digital technologies and online platforms to support remote collaboration, is an important step for the future.

This research recommends that the Faculty of Engineering at Universitas Indonesia continue to strengthen collaboration with various Penta Helix actors to ensure the success of open innovation projects in the future. For academics, it is essential to focus on research and development of technologies that meet the needs of industry and society. Universities should also enhance synergy with industry through more intensive knowledge and technology transfer. Industry, on the other hand, needs to provide financial support and market access for innovation results, as well as collaborate with universities in research and development. The government is expected to continue providing supportive regulations and incentive policies that can expedite the implementation of innovation results. Additionally, the role of mass media is crucial in disseminating information about ongoing innovations to raise awareness and promote adoption by the community. The public itself needs to be actively involved in providing feedback and adopting technologies that emerge from this collaboration.

Moreover, this research finds that one of the main challenges in Penta Helix collaboration is the coordination and alignment of goals among actors. Therefore, facilitators are needed to bridge communication and coordination between various actors to ensure that common objectives can be achieved. The collaboration model developed from this research can serve as a reference for other open innovation projects in Indonesia, particularly those related to environmentally friendly technologies such as electric buses. With these recommendations, it is hoped that the collaboration among universities, industries, the government, mass media, and the community can be more effective and sustainable, thus contributing to the enhancement of national competitiveness and economic progress through open innovation.

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