Application of Multi-Level Perspective Theory in Sustainable Development: A Case Study of Oyster Shell Waste Valorization in Taiwan

Chih-Ming Hung

Assistant Research Fellow, The Third Research Division (Taiwan Economy), Chung-Hua Institution for Economic Research

Chia-Hui Lin

Analyst, The Third Research Division (Taiwan Economy), Chung-Hua Institution for Economic Research

Hsin-Jung Lu

Research Associate, The Third Research Division (Taiwan Economy), Chung-Hua Institution for Economic Research

Tsungche Wei

Associate Research Fellow, The Third Research Division (Taiwan Economy), Chung-Hua Institution for Economic Research

Abstract

This study applies the Multi-Level Perspective (MLP) framework to analyze oyster shell circular economy initiatives in Taiwan, examining three diverse companies: a state-owned enterprise, a small-to-medium sized textile manufacturer, and a large plastics corporation. We explore how innovations in oyster shell waste valorization interact across macro (landscape), meso (regime), and micro (niche) levels. Our findings reveal that while micro-level innovations drive change, meso-level structures often present regulatory and market acceptance barriers. The study highlights the critical role of multi-level interactions in circular economy transitions and underscores the importance of collaboration between large enterprises and SMEs in accelerating innovation diffusion. Key insights include: (1) the crucial role of innovation-driven approaches, (2) the need for institutional support and regulatory flexibility, (3) the potential of cross-sector collaborations, and (4) the importance of market cultivation strategies for circular economy products. This research contributes to understanding socio-technical transitions in the circular economy context and offers practical implications for policymakers and industry stakeholders, emphasizing the need for coordinated efforts across multiple levels to foster sustainable resource utilization.

Keywords: Multi-level Perspective, Circular Economy, Oyster Shell Waste, Sustainable Development, Socio-technical Transitions

1. Introduction

In the context of global climate change and resource scarcity, circular economy has gained increasing attention as a new model of economic development (Geissdoerfer et al., 2017). The circular economy emphasizes efficient resource utilization and regeneration to achieve coordination between economic development and environmental protection. The European Union proposed the "Circular Economy Action Plan" in 2015 and further released the "New Circular Economy Action Plan" in 2020, focusing on seven key areas including electronics, batteries, packaging, and plastics. The Netherlands proposed the "Government-wide Programme for a Circular Economy" in 2016, aiming to achieve a fully circular economy by 2050. The Scottish government introduced the "A Circular Economy Strategy" strategy in 2016, prioritizing the transformation of four key areas: food and drink, remanufacturing, construction, and energy infrastructure. Japan, as early as 2000, proposed the "Sound Material-Cycle Society" policy, establishing a comprehensive legal system for a circular society.

Taiwan has actively promoted circular economy-related policies in recent years. At the central government level, the "5+2 Innovative Industries Policy" was proposed in 2016, which includes the "Circular Economy Promotion Plan" focusing on promoting "circular industrialization" and "industrial circulation." In 2022, "Taiwan's Pathway to Net-Zero Emissions in 2050" was announced, listing circular economy as one of the key strategies. In 2023, the Ministry of Environment proposed the "Resource Recycling with Zero Waste" key strategic action plan, setting three major goals: "sustainable consumption and production," "improving resource usage efficiency," and "value-added treatment of waste." Local governments have also promoted circular economy initiatives in response to local characteristics. For instance, Kaohsiung City is actively building a new materials circular hub and promoting the "Demonstration Circular Industrial Park." Tainan City is dedicated to water resource recycling and reuse while constructing the Shalun Smart Green Energy Science City. Miaoli County has proposed the "Waste Recycling Treatment Overall Park Project" and is promoting innovative approaches such as using black soldier fly (Hermetia illucens) to decompose kitchen waste. Yilan County has made breakthroughs in kitchen waste processing and reuse, as well as the reuse of incineration bottom ash. Pingtung County is promoting the use of livestock manure slurry and biogas residues as agricultural fertilizers and developing a proper treatment system for agricultural waste.

This study selected three Taiwanese companies with outstanding performance in the circular economy field as research subjects. We apply the Multi-Level Perspective (MLP) framework for analysis, obtaining data through personal interviews, news reports, and academic literature. MLP is a powerful tool for understanding socio-technical system transitions, dividing the transition process into micro (niche), meso (regime), and macro (landscape) levels (Geels, 2011). The micro-level represents emerging innovations and technologies, the meso-level represents existing mainstream systems and practices, and the macro-level represents the broader social, economic, and political context. Through this framework, we can more comprehensively understand the opportunities and challenges faced by companies in promoting circular economy innovations, and how these innovations interact with existing systems and the broader social context.

The purpose of this study is to explore how these three companies promote circular economy innovations in complex socio-technical systems through an in-depth analysis of their practices in oyster shell reuse. We will focus on their technological innovation processes, product applications, collaboration methods with other stakeholders, and the difficulties encountered and solutions found in this process. Through this analysis, we hope to provide valuable insights for other companies, policymakers, and researchers to promote the further development of the circular economy.

The remainder of the article is organized as follows. Section 2 briefly reviews the application cases of the MLP method in green transitions, Section 3 describes the current situation of oyster shells in Taiwan and the reuse of oyster shells by case companies, Section 4 conducts analysis and discussion using the MLP framework, and Section 5 presents discussions and recommendations.

2. Review of MLP Application in Green Transitions

2.1. Basic Framework of MLP Theory

The Multi-Level Perspective (MLP) framework offers a nuanced approach to analyzing socio-technical system transitions. This theoretical model, initially proposed by Rip and Kemp (1998) and subsequently elaborated by Geels (2002), conceptualizes the transition process as a dynamic interaction among three hierarchical levels: micro (niche), meso (regime), and macro (landscape) (Geels, 2019).

At the micro level, or niche, innovation and experimentation flourish. This stratum serves as an incubator for nascent technologies, practices, or organizational forms, shielding them from mainstream market selection pressures. The early stages of electric vehicle development exemplify such a protected environment.

The meso level, or regime, represents the incumbent socio-technical system. This encompasses a complex interplay of elements, including established technologies, market structures, policy frameworks, user practices, cultural significances, and infrastructure. The contemporary automotive transportation system, dominated by internal combustion engines, illustrates a typical socio-technical regime.

The macro level, or landscape, embodies the broader exogenous environment. This stratum encompasses macroeconomic trends, deeply ingrained cultural patterns, and macro-political developments. The growing societal awareness of climate change, for instance, constitutes a significant landscape factor influencing energy transitions.

MLP theory posits that transitions typically begin with innovations at the micro level, which under certain conditions may break through to the meso level, eventually leading to a transformation of the entire system. This process usually requires pressure from the macro level to create windows of opportunity (Geels & Schot, 2007). Geels (2002) illustrated this process with the example of the transition in shipping from the late 19th to early 20th century. Steam ships initially appeared as a niche innovation, mainly used for inland waterways. As technology improved and infrastructure developed (such as coal refueling stations), steam ships gradually entered the ocean shipping market. Meanwhile, macro-level factors such as industrialization and growth in international trade created opportunities for steam ships. Eventually, steam ships replaced sailing ships as the dominant shipping technology.

2.2. Review of MLP Applications in Sustainable Development

The MLP theory has been widely applied in the field of sustainable development, particularly in areas such as energy, transportation, and agri-food systems. Here are several specific application examples:

2.2.1. Energy Transition

MLP has been widely used to analyze the transition to low-carbon energy systems. Geels et al. (2016) used MLP to analyze the low-carbon transition of electricity systems in Germany and the UK. They found that the transition paths in the two countries differed significantly, reflecting different policy approaches and socio-political contexts. In the German case, the development of renewable energy underwent a "bottom-up" process. Initially, wind and solar energy emerged as niche innovations, supported by environmentalists and farmers. Over time, these technologies gradually matured and received policy support (such as feed-in tariff systems). Meanwhile, landscape events such as the Fukushima nuclear accident created opportunities for renewable energy. Eventually, renewable energy successfully challenged the traditional energy system dominated by fossil fuels and nuclear power. In contrast, the UK's low-carbon transition was more of a "top-down" process led by the government. The government promoted the transition by setting carbon emission targets and implementing various policy instruments (such as renewable energy obligations). This approach led to the development of more large-scale projects (such as offshore wind farms) rather than distributed small-scale projects.

2.2.2. Bioeconomy

Imbert et al. (2019) used the MLP framework to analyze the development of the bioplastics industry in Italy and Germany. They found that the development paths in the two countries differed, closely related to their respective policy strategies. In Italy, the government adopted a "bottom-up" strategy, mainly stimulating the bioplastics market through demand-side policies (such as banning non-biodegradable shopping bags). This approach effectively created market demand for bioplastics, promoting rapid industry development. In contrast, Germany adopted a "top-down" strategy, mainly promoting the development of bioplastics technology through large public R&D investments. While this approach promoted technological innovation, it was slower in terms of market promotion. This study highlights the important role of policy in shaping transition pathways and demonstrates the value of MLP in comparing transition processes across different countries.

2.2.3. Waste Management

Raven (2007) used MLP to analyze the co-evolution of waste and electricity systems in the Netherlands, providing a new perspective for understanding the transition of waste management systems. The study found that from the late 1960s to the early 21st century, the Dutch waste management system transitioned from simple landfilling to more complex recycling and energy recovery systems. This transition was closely related to the development of the electricity system. For example, the development of waste incineration power generation technology provided new options for waste management while also providing new energy sources for the electricity system. This study highlights the importance of interactions between different socio-technical systems in the transition process, which is an important extension of MLP theory.

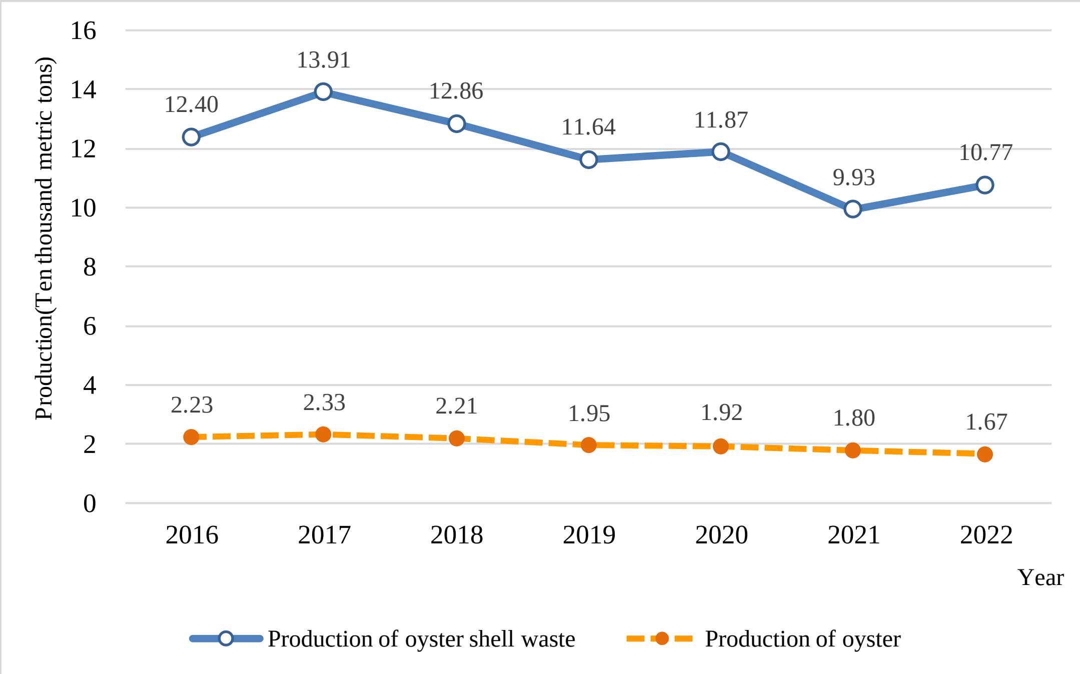
2.2.4. Bioenergy

Geels and Raven (2006) applied MLP to analyze the non-linear trajectory of biogas development in the Netherlands, revealing the complexity of innovation development processes. The study traced the development of biogas technology in the Netherlands from 1973 to 2003. They found that biogas technology experienced several ups and downs. Initially, it received attention as a solution to the energy crisis. However, as oil prices declined, public interest gradually waned. Later, with the increase in environmental awareness, biogas regained attention, but this time mainly as a waste treatment method. This study emphasizes the important role of expectations in innovation development and how these expectations change over time and context. It also demonstrates the value of MLP in analyzing long-term technological trajectories.

3. Current Situation of Oyster Shell Utilization in Taiwan and Case Studies

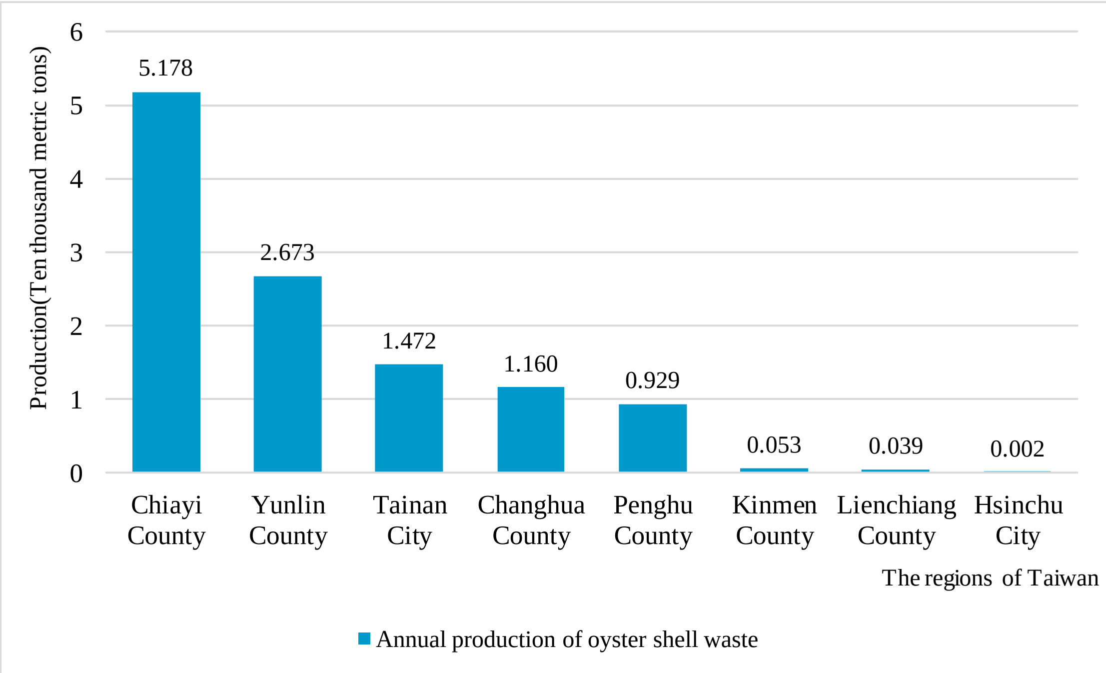
3.1. Oyster Shell Production and Distribution by County in Taiwan

Oyster farming is a traditional industry in the coastal areas of southwestern Taiwan, contributing to the development of fishing villages. However, the shells left after shucking oysters amount to six times the weight of the oysters themselves. According to the Ministry of Agriculture's "Agricultural Solid Waste of Green National Income Account" statistics, oyster shells are currently the most abundant biological fishery waste in Taiwan, with an annual production of over 100,000 tons (Figure 1). The latest data from the Ministry of Agriculture's "Agricultural Residue Resource Information Platform" shows that the top eight counties and cities in Taiwan with the highest annual oyster shell production are Chiayi County, Yunlin County, Tainan City, Changhua County, Penghu County, and Kinmen County (Figure 2).



Source：Taiwan Agriculture Statistical Platform，
https://agrstat.moa.gov.tw/sdweb/public/common/Download.aspx。

Figure 1 Production of oyster shell waste and oyster by year



Source：Taiwan Information Platform - Agricultural Residues to Resources，
https://agricycle.tier.org.tw/Encyclopedia/More/00ea9663654948bfac4ab4a173036b94。

Figure 2 Annual production of oyster shell waste by Taiwan's regions

The improper disposal of oyster shell waste presents significant environmental challenges, including spatial occupation and the potential proliferation of disease vectors such as mosquitoes and other insects. This issue is particularly salient in major oyster production regions, which consequently bear the primary responsibility for managing discarded oyster shells. In response, various local governments have implemented targeted policies, including the establishment of temporary storage facilities for oyster shell waste and the promotion of shell reuse initiatives among businesses. These measures aim to mitigate environmental pollution while simultaneously fostering circular economy principles.

Despite these efforts, the current utilization of discarded oyster shells remains predominantly in low value-added applications. Data from 2022 reveals that approximately 51% of recycled oyster shells were repurposed for animal feed, 20% for seedling cultivation medium, 19% for compost, and 10% for miscellaneous uses such as aquaculture pond disinfection, water purification, and road base materials. Notably, regulatory constraints preclude the use of oyster shell derivatives in potentially high value-added sectors such as food, cosmetics, pharmaceuticals, and medical chemical products.

Notwithstanding these limitations, a select cohort of innovative enterprises has identified novel application potentials for oyster shells. These companies are endeavoring to transition discarded oyster shells from their current niche status into the established socio-technical regime, operating within the broader landscape of environmental sustainability and resource efficiency.

From the international to the local level, the circular economy has become an important direction for development. As an important agricultural waste resource, the reuse of oyster shells can not only solve environmental problems but also create new economic value, representing an important example of implementing circular economy concepts.

3.2. Cases Description

This study selected three companies as research subjects based on their significant innovative practices in the field of oyster shell reuse. These organizations represent efforts to promote circular economy principles by companies of varying scales and diverse industry backgrounds. The selection provides a cross-sectional view of how different entities approach the challenge of valorizing oyster shell waste within their respective operational contexts.

3.2.1. A Company

A company is a state-owned company established in 1946, originally focusing on sugar and sugar by-product production and sales. Recently, it has actively promoted diversification and transformation, establishing multiple business divisions including sugar, biotechnology, refined agriculture, oil products, livestock, leisure and recreation, and commodity marketing. Its innovation in oyster shell reuse began with a concern for environmental issues and insights into circular economy opportunities. The company established Taiwan's first new-style "Oyster Shell Processing Plant" with an annual processing capacity of 50,000 tons. This initiative not only solves the environmental problem of discarded oyster shells but also creates new economic value.

At the technological level, A company's innovation is manifested throughout the entire processing workflow. The processing plant employs low-carbon energy sources (natural gas) for oyster shell calcination, which is more environmentally friendly compared to traditional heavy oil combustion. To control pollution, the facility is equipped with three sets of environmental dust collection systems, achieving a total particulate matter removal rate of 99.91%. This highly efficient pollution control not only complies with environmental requirements but also enhances product quality. A company processes oyster shells into calcium carbonate raw materials, upon which they have developed a series of innovative products, including antibacterial shell powder, 3D printing substrates, eco-friendly wood-plastic composites, and high-quality oyster shell handmade soap. The development of these products demonstrates A company's capacity to transform waste into high value-added products, while also reflecting the company's acute insight into market demands.

In promoting innovation, A company has adopted an active cooperation strategy. The company provides standardized oyster shell powder to downstream manufacturers for application through industry-academia-research cooperation and collaborates with leading companies in various industries. This cooperation model not only expands the scope of oyster shell reuse but also promotes innovation throughout the entire industry chain.

A company, however, encountered significant challenges during this process. The most notable issue was the inconsistent definition of discarded oyster shells across various counties and cities, resulting in disparate management practices. This heterogeneity manifested in complications surrounding the cross-regional transportation and processing of oyster shell waste.

In response to this challenge, A company implemented a proactive communication strategy, engaging in dialogue with local governments to ultimately achieve consensus. Concurrently, the company is advocating for change at a higher administrative level, actively liaising with the Ministry of Agriculture, the competent authority, to promote the revision of pertinent regulations. This initiative aims to foster a policy environment more conducive to circular economy development.

3.2.2. B company

B company is a Taiwanese plastics company established in 1954, mainly producing polyvinyl chloride resins and other intermediate plastic products. Its innovation in oyster shell reuse fully utilizes the company's advantages in the plastics field, demonstrating the potential of large enterprises in promoting the circular economy. The company's innovation process began with transforming discarded oyster shells into "antibacterial shell powder," involving the development of high-temperature calcination and special grinding technologies.

In terms of technological advancements, a crucial breakthrough for B company is their successful integration of shell powder with various plastic raw materials, resulting in the development of antibacterial plastic composites. This material innovation not only enhances the added value of plastic products but also pioneers new applications for discarded oyster shells. This innovative process exemplifies B company's capacity to apply its expertise in plastics to circular economy initiatives. Leveraging these technological innovations, B company has developed a range of products, including "standard grade," "moisture-resistant grade," and "water-resistant grade" antibacterial shell powders, as well as "antibacterial shell powder extract." These products find wide-ranging applications across diverse sectors, encompassing household items, 3C electronics and appliances, medical equipment, construction materials, and transportation. This diversified product line not only maximizes the utilization value of discarded oyster shells but also provides eco-friendly solutions for various industries.

In promoting innovation, B company has adopted an active cooperation strategy, especially with small and medium-sized enterprises. The company works closely with SMEs, jointly conducting R&D tests, providing technical support and quality control, and assisting SMEs in conducting product antibacterial tests. This cooperation model not only accelerates the diffusion of innovation but also promotes the upgrading of the entire industry chain. In addition, B company provides "sales tags" to SMEs cooperating with it, allowing consumers to understand that the "antibacterial shell powder" added to the product is manufactured by a large enterprise, natural and non-toxic, and incorporates environmental protection and circular concepts. This not only provides purchase assurance to end consumers but also helps SMEs rapidly increase their brand visibility and open up the consumer market, achieving mutual benefits and win-win results.

In the course of its operations, B company encountered several systemic challenges. A significant issue was the prevalence of unauthorized temporary storage sites for discarded oyster shells. This not only compromised the quality and supply stability of raw materials but also engendered unfair competition within the sector.

In response to this challenge, B company has advocated for enhanced governmental oversight to foster a more equitable and standardized market environment. Another considerable obstacle was the regulatory constraints on the application scope of waste reuse. To address this, the company has proactively urged the government to consider a measured relaxation of relevant regulations, with the aim of facilitating circular economy development.

3.2.3. C Company

C company was established in 2010 and is a well-known professional fabric manufacturer and trader in the industry. Its innovation process in the field of oyster shell reuse demonstrates the potential and resilience of small and medium-sized enterprises in the circular economy field. The company invested years in research and development, successfully combining oyster shells with recycled polyester to develop a new type of environmentally friendly material. This innovation not only reflects the company's technological strength but also its long-term commitment to sustainable development.

At the technological level, a significant breakthrough for C company lies in their establishment of a technique for grinding oyster shells to an ultra-fine consistency. This refined processing technology is crucial for the application of oyster shells in textiles, ensuring the quality and comfort of the final product. The development process of this technology was fraught with challenges, requiring extensive experimentation and optimization, which exemplifies the company's perseverance and patience in the innovation process. Building upon these technological innovations, C company has developed the "Seawool®" brand, introducing a series of thermal insulation fabrics. Additionally, the company has developed "Hulk Bio-Ceramic," a bio-ceramic antibacterial powder. These products not only exhibit excellent functionality but also incorporate eco-friendly concepts, demonstrating the company's ability to transform circular economy principles into tangible products.

In promoting innovation, C company adopted a flexible cooperation strategy. The company outsourced the front-end processing of oyster shells to local operators, allowing the company to focus on the development of core technologies. At the same time, the company actively assists customers in product development and testing. This close customer cooperation not only accelerates product marketization but also helps continuously improve product performance.

As a small and medium-sized enterprise (SME), Company C encountered numerous challenges during its innovation process. The most significant obstacles were the insufficiency of funds and limited production capacity in the initial stages of research and development. To address these constraints, the company implemented a flexible strategy, leveraging income from ancillary business operations to support R&D investments.

Another critical challenge was the substantial cost associated with product certifications. In response, the company adopted a strategic approach, selectively pursuing certifications based on specific customer requirements. This judicious strategy allowed the company to effectively manage costs while simultaneously ensuring access to key markets.

These challenges and the company's adaptive responses exemplify the unique hurdles faced by SMEs in innovation-driven sectors and highlight the importance of strategic resource allocation and market-oriented decision-making in navigating the complex landscape of product development and commercialization.

4. MLP Analysis and Discussion

4.1. MLP Analysis

By examining these three cases through the lens of the MLP, we can gain a more comprehensive understanding of the complex environment in which these companies are promoting circular economy innovations, and how they are driving change at different levels.

At the micro (niche) level, all three companies have demonstrated significant innovation capabilities. A company established a new oyster shell processing plant and developed a series of innovative products based on calcium carbonate. C company successfully combined oyster shells with recycled polyester to develop new eco-friendly textile materials. B company utilized its advantages in the plastics field to develop antibacterial shell powder and antibacterial plastic composite materials. These innovations are not only reflected in the technological aspect but also extend to product development and business model innovation. For example, B company's "sales tag" strategy is an innovative marketing approach that helps SMEs increase brand visibility. These micro-level innovations provide important momentum and possibilities for the transformation of the entire socio-technical system.

At the meso (regime) level, we can observe how existing systems both support and hinder these innovations. For instance, the existing plastics industry provided B company with a technological foundation and market channels for its innovations, but at the same time, regulatory restrictions on waste reuse became obstacles to innovation. All three companies faced regulatory challenges to varying degrees, such as the cross-regional waste transportation issues encountered by A company and the application scope limitations faced by B company. This reflects the contradictions between existing institutional frameworks and emerging circular economy practices. However, these companies are also actively promoting institutional change, such as A company's communication with local governments and the Ministry of Agriculture, and B company's call for relaxation of relevant regulations. These efforts demonstrate how innovators are attempting to change meso-level structures to create an environment more conducive to the development of the circular economy.

In terms of industry structure, we can see that large enterprises (such as A company and B company) are playing a leading role, driving SMEs to participate in the circular economy. This model of collaboration between large and small enterprises is forming a new industrial ecosystem that helps accelerate the transformation of the entire industry. Meanwhile, SMEs like C company are finding their own positioning, participating in this transformation process by focusing on innovations in specific areas.

Market rules and user practices are also important components of the meso level. All three companies are working to increase consumer awareness and acceptance of oyster shell products, reflecting the challenges of changing existing consumption patterns. For example, the "sales tags" provided by B company are an attempt to educate consumers. These efforts show how innovators are trying to reshape market rules and consumer behavior to support the promotion of circular economy products.

At the macro (landscape) level, we can see the influence of broader social trends and policy environments on these innovations. The popularization of circular economy and sustainable development concepts has provided a favorable external environment for these companies' innovations. Government support for waste reuse has also created a favorable policy atmosphere. However, the high requirements of international markets for eco-friendly products also bring challenges, especially for companies looking to enter international markets. This reflects the complexity faced by corporate innovation in the context of globalization.

It is worth noting that these three levels are not static, but rather interact and co-evolve. For example, micro-level innovations may gradually change meso-level rules and practices, while macro-level changes (such as increased environmental awareness) create opportunities for micro-level innovations. This dynamic, multi-level interaction is the core insight of the MLP framework, helping us to understand the complexity of socio-technical transitions more comprehensively.

4.2. Discussion

Through the analysis of these three companies, we can draw several important insights that not only enrich our understanding of circular economy innovation but also provide valuable implications for other companies and policymakers.

First, innovation-driven approaches play a key role in circular economy transitions. All three companies have demonstrated strong innovation capabilities, from technological innovation to product innovation to business model innovation. This echoes the circular business model innovation theory proposed by Bocken et al. (2016), emphasizing the core role of innovation in driving the circular economy. For example, A company's approach of transforming discarded oyster shells into various high value-added products demonstrates how to maximize resource value through innovation. C company's technological innovation of combining oyster shells with recycled polyester shows how material innovation can drive the circular economy. These cases indicate that companies need to continuously invest in R&D and explore new technologies and business models to maintain competitiveness in the circular economy transition.

Second, multi-level interactions play a crucial role in circular economy innovation. As emphasized by Geels (2011) in the MLP framework, companies' innovation activities are influenced by factors at micro, meso, and macro levels. For instance, B company's innovation benefited from the company's advantages in the plastics field (meso level) while also being driven by the popularization of circular economy concepts (macro level). C company's innovation was influenced by the increased global market demand for eco-friendly textiles (macro level). This multi-level interaction reminds us that companies need to consider factors at all levels comprehensively when promoting circular economy innovation and seek synergies between these factors.

Third, institutional barriers remain one of the main challenges facing circular economy innovation. This is consistent with the findings of Kirchherr et al. (2018), who pointed out that regulatory barriers are one of the main challenges in implementing the circular economy. In our cases, all three companies faced different levels of regulatory restrictions, such as inconsistent definitions of waste, cross-regional transportation restrictions, and application scope limitations. This reflects the contradictions between existing institutional frameworks and circular economy innovations. However, it's worth noting that these companies did not passively accept these limitations but actively communicated with the government to promote institutional change. This approach is worth learning from for other companies, while also reminding policymakers of the need for more flexible and innovation-supportive institutional design.

Fourth, collaboration between large and small enterprises plays an important role in driving circular economy transitions. Our cases show that large enterprises can play a leading role in driving SMEs to participate in the circular economy. For example, B company helps SMEs develop new products by providing technical support and quality control. This collaboration model not only accelerates the diffusion of innovation but also promotes the upgrading of the entire industry chain. At the same time, SMEs like C company are also finding their own positioning, participating in this transition process by focusing on innovations in specific areas. This model of collaboration between large and small enterprises provides a new perspective for understanding the role of enterprises in industry transitions.

5. Conclusion and Policy Recommendations

The application of the Multi-Level Perspective to oyster shell waste valorization in Taiwan reveals a complex, dynamic process of socio-technical transition towards a circular economy. Through the examination of three diverse companies - a state-owned enterprise, a large plastics corporation, and a small-to-medium sized textile manufacturer - this study illuminates how innovations at the micro (niche) level interact with meso (regime) and macro (landscape) factors to drive systemic change.

The analysis underscores the critical role of innovation as a driving force in circular economy transitions. All three companies demonstrated significant technological and business model innovations, highlighting the importance of niche-level experimentation. However, these innovations often encounter regulatory challenges at the meso level, particularly in cross-regional waste management and product application scope, despite macro-level support for circular economy principles.

The cases also emphasize the importance of multi-actor collaboration in accelerating innovation diffusion and industry transformation. The synergistic relationship between large enterprises and SMEs proved instrumental in overcoming barriers and fostering a more inclusive innovation ecosystem. Nevertheless, all three companies faced challenges in cultivating market acceptance for their innovative products, indicating the need for strategies to reshape consumer behavior and market rules.

This study reinforces the MLP theory's emphasis on the importance of alignments across levels for successful transitions. The interplay between macro-level trends, meso-level structures, and micro-level innovations was evident throughout the cases, demonstrating how societal shifts towards sustainability created opportunities for niche innovations to emerge and potentially transform existing regimes.

To address the challenges and capitalize on the opportunities identified in this study, a comprehensive set of policy interventions is recommended. These suggestions aim to create a more conducive environment for circular economy innovations in oyster shell valorization, potentially accelerating Taiwan's transition towards a more sustainable and circular economy.

Firstly, regulatory harmonization is crucial. Establishing a national-level framework for oyster shell waste classification and management would address the challenges faced by companies in cross-regional transportation and processing, ensuring consistent practices across different localities. This could be complemented by the implementation of regulatory sandboxes specifically for circular economy innovations, allowing controlled testing of new applications and helping companies overcome limitations on the application scope for waste reuse.

Support for SME innovation is another key area for policy intervention. Developing targeted financial and technical support programs for SMEs engaged in circular economy innovations would foster a more inclusive innovation ecosystem. This could be coupled with incentives for large enterprise-SME collaborations, such as tax breaks or grants for joint circular economy projects, building on the successful model demonstrated in the case studies.

To address market acceptance challenges, establishing a national certification system for products using recycled oyster shells could provide consumer assurance and product differentiation. This could be further supported by preferential public procurement policies for such products, creating a stable demand for innovative circular economy solutions.

Finally, establishing cross-sector innovation platforms and international collaboration initiatives could facilitate knowledge sharing and accelerate innovation diffusion. These platforms could help address challenges at multiple levels of the socio-technical system and assist companies in meeting high international market standards for eco-friendly products.

By implementing these policy suggestions, Taiwan could create a more favorable environment for circular economy innovations, not only in oyster shell valorization but potentially across other sectors as well. This holistic approach, addressing challenges at all levels of the MLP framework, could significantly contribute to Taiwan's transition towards a more sustainable and circular economy.

References

Bocken, N. M. P., De Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering, 33*(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy, 31*(8–9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions, 1*(1), 24–40. https://doi.org/10.1016/j.eist.2011.02.002

Geels, F. W. (2019). Socio-technical transitions to sustainability: A review of criticisms and elaborations of the Multi-Level Perspective. *Current Opinion in Environmental Sustainability, 39,* 187–201. https://doi.org/10.1016/j.cosust.2019.06.009

Geels, F. W., & Raven, R. (2006). Non-linearity and expectations in niche-development trajectories: Ups and downs in Dutch biogas development (1973–2003). *Technology Analysis & Strategic Management, 18*(3–4), 375–392. https://doi.org/10.1080/09537320600777143

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy, 36*(3), 399–417. https://doi.org/10.1016/j.respol.2007.01.003

Geels, F. W., Kern, F., Fuchs, G., Hinderer, N., Kungl, G., Mylan, J., Neukirch, M., & Wassermann, S. (2016). The enactment of socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014). *Research Policy, 45*(4), 896–913. https://doi.org/10.1016/j.respol.2016.01.015

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy–A new sustainability paradigm? *Journal of Cleaner Production, 143,* 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Imbert, E., Ladu, L., Tani, A., & Morone, P. (2019). The transition towards a bio-based economy: A comparative study based on social network analysis. *Journal of Environmental Management, 230,* 255–265. https://doi.org/10.1016/j.jenvman.2018.09.068

Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., & Hekkert, M. (2018). Barriers to the circular economy: Evidence from the European Union (EU). *Ecological Economics, 150,* 264–272. https://doi.org/10.1016/j.ecolecon.2018.04.028