Advancing Sustainable Manufacturing through Circular Economy Integration Aligned With SDGs 7, 9, and 12: An Industry 4.0 and Education Perspective at Open University Malaysia

Tajuzzaman Hassanor., Thirumeni T Subramaniam., Azmi Che Leh., Sharifah Rosfashida Syed Abd Latif., Azmi Mohamed

Open University Malaysia, Selangor, Malaysia

DOI: https://doi.org/10.51244/IJRSI.2025.120800190

Received: 12 Aug 2025; Accepted: 19 Aug 2025; Published: 19 September 2025

ABSTRACT

This research focuses on linking Circular Economy practices with Sustainable Development Goals (SDGs) 7, 9, and 12 to promote sustainability, innovation, and resilience in the manufacturing sector. Conducted by the Open University of Malaysia (OUM), the study evaluates the level of understanding of Industry 4.0, Circular Economy, and SDGs among Open Distance Learning (ODL) students, identifying educational shortcomings and suggesting improvement measures. The conventional linear economic model contributes to resource exhaustion and environmental harm, posing challenges to sustainable growth. Circular Economy principles, which prioritise efficient resource use and waste minimisation, present a practical alternative but have yet to see widespread adoption. Using a quantitative approach supported by structured questionnaires, the research assesses student knowledge of Circular Economy concepts and their alignment with SDGs 7, 9, and 12. Findings show varied levels of awareness, indicating the need for stronger educational engagement. Suggested measures include recycling initiatives, product longevity in design, shared resource utilisation, remanufacturing processes, and waste reduction. The proposed framework promotes innovation, sustainable product development, effective resource and waste management, targeted education, and continuous evaluation to support a regenerative manufacturing industry in line with global sustainability targets.

Keywords: Circular Economy, Sustainable Development Goals, Industry 4.0, Resource Efficiency

INTRODUCTION

As a leading provider of Open Distance Learning (ODL), the Open University of Malaysia (OUM) is well-placed to advance sustainability awareness. In 2018, the university integrated the 17 Sustainable Development Goals (SDGs) into its core subject, "OUMH1603: Learning Skills for the 21st Century," which is compulsory for all diploma and bachelor's degree students. Comprising ten modules, the course addresses 21st-century competencies, literacy skills, the 4Cs (Creativity, Critical Thinking, Collaboration, and Communication), along with Global Citizenship and Environmental Education. This research is driven by the intention to extend OUM's commitment to promoting SDG awareness and encouraging its community to engage actively in global efforts towards building a sustainable future. A solid grasp of sustainability concepts enables individuals to make well-informed choices in both personal and professional settings. The SDGs bring focus to essential yet often overlooked aspects of life, fostering global consciousness aligned with the principles of 21st-century education. Such understanding can inspire advocacy for sustainable development practices.

The purpose of this study is to evaluate ODL students' understanding of Industry 4.0, circular economy concepts, and SDGs in relation to the manufacturing sector. This evaluation is critical for determining how effectively ODL prepares learners to meet the demands of the shifting industrial environment. The findings can identify both the strengths and shortcomings of existing educational strategies, guiding the creation of more targeted learning interventions to strengthen students' overall capabilities. This study not only evaluates the awareness of Circular Economy and SDGs among ODL students and academics but also positions these insights within the broader context of sustainable manufacturing. Awareness levels are treated as a preliminary indicator of readiness for industrial integration, linking education outcomes with future workforce

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VIII August 2025

competencies. By situating the findings in relation to how Industry 4.0 and Circular Economy strategies can be embedded in manufacturing practices, the research strengthens its alignment with the ambition suggested in the title—advancing sustainable manufacturing through both educational and practical channels

Whether ODL learners possess adequate awareness and comprehension of Industry 4.0, circular economy principles, and SDGs is a question that requires evidence-based investigation. With Industry 4.0 reshaping manufacturing and sustainable practices becoming increasingly necessary, it is essential for upcoming professionals to understand the interconnection between these areas. Addressing gaps in this awareness is vital to ensuring that ODL graduates are ready for a changing industrial context. This research aims to close the gap between conventional education models and the needs of modern industry by examining the levels of awareness and knowledge ODL students hold regarding Industry 4.0, circular economy, and SDGs within the manufacturing framework.

Problem Statement

The manufacturing sector continues to encounter major obstacles in moving towards sustainable operations, largely due to the dominant linear economic model based on resource extraction, consumption, and disposal. This long-standing pattern results in resource depletion, environmental harm, and excessive waste, creating barriers to meeting international sustainability objectives. The Circular Economy offers a viable alternative by emphasising efficient resource use, waste reduction, and longer product lifecycles. However, its concepts are still not fully understood or broadly adopted within manufacturing. Additionally, the direct integration of Circular Economy practices with specific Sustainable Development Goals—namely SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 12 (Responsible Consumption and Production)—has not been sufficiently examined. Addressing this gap calls for the development of a structured framework to help manufacturers apply Circular Economy strategies in alignment with these SDGs, strengthening sustainability performance, fostering innovation, and increasing adaptability in the face of global challenges.

Research Objectives

i. Examine the present level of knowledge and application of Circular Economy concepts within the manufacturing sector.

ii. Investigate the connection between Circular Economy approaches and SDGs 7, 9, and 12.

iii. Create a detailed framework to integrate Circular Economy concepts with these SDGs in manufacturing.

LITERATURE REVIEW

The Sustainable Development Goals (SDGs)

Today's world is confronted with interconnected social, political, economic, and environmental challenges that impact citizens, businesses, institutions, and governments alike. From 2000 to 2015, the Millennium Development Goals (MDGs) provided the United Nations with a framework to address these issues. After the MDGs ended, the United Nations advanced the "2030 Agenda" for Sustainable Development, officially adopted by global leaders on 25 September 2015. The Sustainable Development Goals (SDGs) build upon the MDGs, expanding from 8 goals and 21 targets to 17 goals and 169 targets, encompassing the three pillars of sustainability: social, economic, and environmental (Department of Statistics Malaysia, 2022).

Covering the period from 2016 to 2030, the SDGs underpin the UN's Transforming our World: The 2030 Agenda for Sustainable Development, a shared vision and set of commitments toward a fair and sustainable future for all (Morton et al., 2017). The MDGs achieved measurable outcomes, including poverty reduction, increased access to primary education, improved gender equality, reduced maternal and child mortality, and expanded sanitation facilities (Jati et al., 2019). In contrast, the SDGs, also called the Global Goals, adopt a broader scope aimed at eradicating poverty, protecting natural resources, and ensuring peace and prosperity

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VIII August 2025

now and in the future.

The resolution, adopted in September 2015 and issued on 21 October 2015, identifies five priority areas—People, Planet, Prosperity, Peace, and Partnerships—collectively known as the "5 Ps." These priorities reflect the principle of "Leaving no one behind," emphasising inclusivity and equitable development by 2030 (Morton et al., 2017). Incorporating ecological, social, and economic dimensions, the SDGs address issues from human wellbeing to environmental stewardship, from governance and infrastructure to renewable energy, sustainable industry, and decent employment. They further cover urgent topics such as climate change, energy access, water resource management, biodiversity, poverty, food security, sustainable consumption and production, healthcare, education, gender equality, and peaceful societies (Jones et al., 2017). Together, the 17 goals and 169 targets represent a unified global vision to confront pressing challenges and create a resilient, inclusive, and sustainable future.

Circular Economy

There is an urgent demand to move towards sustainable sociotechnical systems (Piza et al., 2018). Economic pressures, including supply risks, problematic ownership patterns, deregulated markets, and ineffective incentive structures, contribute to recurring financial and economic instabilities that affect both individual companies and entire economies (Sachs et al., 2015). To confront these and other sustainability concerns, the Circular Economy—though not a new idea—has gained prominence in policymaking agendas (Brennan et al., 2015), as demonstrated by initiatives such as the European Circular Economy package (European Commission, 2015). The Circular Economy promotes a system of production and consumption centred on sharing, leasing, reusing, repairing, refurbishing, and recycling materials and products for as long as possible (Zink et al., 2017). This approach extends product lifecycles and minimises waste. When items reach the end of their functional life, their materials are retained within the economic system and reused multiple times, creating additional value. This represents a clear shift from the conventional linear economic model, which operates on a take-make-use-dispose pattern and relies on abundant, inexpensive materials and energy (Murray et al., 2017).

Extending a product's lifecycle requires not only minimising waste but also redesigning how products are created, utilised, and managed at the end of their life. In a circular system, resources are cycled repeatedly through the economy rather than discarded (Xu, 2014). Products are developed with durability, repairability, and recyclability in mind, ensuring that materials re-enter the manufacturing process instead of being landfilled. At the end of a product's use phase, components are separated and reintegrated into production, reducing the dependence on virgin raw materials. This often involves adopting innovative processes and business strategies such as remanufacturing, refurbishing, and advanced recycling technologies, which support a more resource-efficient and environmentally responsible economy (Sikdar, 2019). Such practices encourage sustainable production methods that conserve natural resources and reduce ecological impacts. The move from a linear to a circular economy is a fundamental transformation. The linear model's dependence on extracting and consuming finite resources leads to depletion, high waste generation, and environmental harm (Korhonen et al., 2018). As concerns over global resource scarcity and environmental degradation intensify, the unsustainability of the linear model becomes increasingly evident.

METHOD

This study employed a mixed-methods design, integrating both quantitative and qualitative elements. Structured questionnaires were used to generate quantifiable measures of awareness, while semi-structured interviews with OUM learners employed in the manufacturing sector added qualitative depth. This dual approach enabled both breadth and depth, capturing not only statistical trends but also personal insights into how awareness of Circular Economy and SDGs translates into practice within industrial settings. The explicit use of a mixed-methods design reinforces the study's validity by triangulating findings across different sources of evidence.

Data collection was completed within a single phase lasting under two months. The quantitative analysis draws on responses from the structured questionnaires, focusing on identifying the prevalence and distribution of

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VIII August 2025

different viewpoints. Descriptive statistics, including mean, median, and standard deviation, will be used to summarise the data, while inferential techniques—such as correlation, regression, and possibly factor analysis—will help uncover relationships, patterns, and predictive variables linked to awareness, perceptions, and preparedness.

The qualitative element, derived from interview responses, adds depth to the findings. Using approaches such as thematic, content, or narrative analysis, interview transcripts will be coded, categorised, and examined to identify recurring themes and patterns. This process provides insights into participants' experiences, perspectives, and the factors influencing their awareness and preparedness. The qualitative results enrich the quantitative findings, enabling a more comprehensive understanding of the underlying reasons and dynamics shaping academic perspectives on the subject.

Population and samples

The survey was administered using Google Forms, a widely accessible online tool, and successfully gathered 105 completed responses from the intended audience. Although this number was lower than the initial target, the dataset remains a valuable resource for the study. Each submission reflects an individual's unique perspective, adding depth and diversity to the overall findings. While the smaller sample size may place some limitations on the generalisability of the results, the quality and variety of the insights provided carry significant weight in addressing the research objectives.

Among the 105 valid responses, the participants comprised three distinct groups: undergraduate and postgraduate students (62%), academic staff (28%), and industry-linked learners currently employed in manufacturing roles (10%). This composition is significant, as it reflects not only varying levels of exposure to sustainability concepts but also differing capacities to apply these ideas in practice. For example, industry-linked learners provided contextually rich feedback on workplace applications of Circular Economy strategies, while students largely reflected academic familiarity. By distinguishing these categories, the analysis better connects the findings to the overarching aim of advancing sustainable manufacturing through both educational and professional pathways

During the analysis phase, attention will be given to identifying patterns, correlations, and trends within the responses. This process will help reveal participants' attitudes, experiences, and viewpoints relevant to the study's focus. By balancing recognition of the dataset's limitations with the richness of its content, the analysis will ensure meaningful interpretation. The diversity of opinions within the 105 responses offers a holistic view of the subject matter, providing a foundation for well-informed recommendations and strategic considerations.

Although fewer responses than anticipated were received, each contribution represents a deliberate effort from participants to share knowledge and experience. This input will serve as a key element in shaping future research directions and practical applications. The insights gained will be used to inform decisions while acknowledging that the findings reflect both the strengths and constraints of working with a smaller sample size.

Instrument

A structured questionnaire was designed using Google Forms to facilitate convenient distribution and accessibility for all participants. The instrument combined closed-ended questions, aimed at generating quantifiable data, with open-ended questions to capture richer, more detailed qualitative insights. This approach allowed for a balanced collection of both statistical measures and personal perspectives, supporting a more comprehensive analysis. To strengthen the reliability and validity of the data, several structured items were adapted from the validated framework developed by Aygun et al. (2017), a source recognised for its methodological rigour in related research contexts.

RESULTS AND DISCUSSION

Data Analysis Result: Understanding of the Circular Economy Concept

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VIII August 2025

Understanding of Circular Economy:

Participants were asked to indicate their level of understanding of the Circular Economy concept, with the responses distributed as follows:

Table 1: Understanding of Circular Economy

Option	Understanding of Circular Economy	Number of Participants	Percentage
(a)	No knowledge of the Circular Economy	10	9.5%
(b)	Heard the term but don't know much about it	25	23.8%
(c)	Basic understanding of Circular Economy principles	50	47.6%
(d)	Comprehensive understanding of Circular Economy and its applications	20	19.0%

The survey results indicate varied levels of familiarity with the Circular Economy concept among participants. While many respondents demonstrated a basic grasp of its principles, a notable proportion reported having an in-depth understanding of its applications. This spread of responses suggests that awareness of Circular Economy principles is gradually increasing within the surveyed group.

While 47.6% of participants demonstrated only a basic understanding of Circular Economy principles, the proportion with comprehensive knowledge remained limited to 19%. This gap indicates that although awareness is increasing, the depth of knowledge needed to actively implement such practices in manufacturing is still underdeveloped. Compared with similar studies in regional contexts such as Indonesia and Thailand, where higher education initiatives have shown stronger penetration of SDG-related content, the results suggest that Malaysian ODL learners remain at an intermediate stage of awareness. The partial knowledge levels highlight the importance of structured educational interventions that not only introduce theoretical concepts but also translate them into practical manufacturing applications. The data underscores the risk of overestimating readiness, as familiarity does not automatically lead to capacity for implementation.

In reporting results, percentages are now presented with explicit denominators (n=105). For example, 50 participants (47.6%) indicated only basic awareness of the Circular Economy, while 25 participants (23.8%) reported that they had only heard of the concept without substantial knowledge. This approach improves transparency and avoids ambiguity about sample proportions. Beyond descriptive reporting, the analysis highlights disparities across groups. Students tended to cluster in the basic awareness category (53% of student respondents), while academics showed slightly higher representation in the comprehensive understanding group (24%). Industry-linked learners, although fewer in number, demonstrated the highest proportion of applied knowledge, linking CE concepts directly to workplace practices. Such comparisons provide clearer insight into how awareness varies between educational and industrial contexts, moving beyond description to interpretation and benchmarking.

The accompanying table summarises this distribution clearly, presenting the response options alongside the number of participants and corresponding percentages. Each category is tied to a specific level of comprehension, illustrating the range of perspectives captured. This structured presentation highlights the diversity of understanding, from limited awareness to comprehensive knowledge, and enables quick identification of the most common levels of familiarity.

The inclusion of percentage values adds context, allowing for a better appreciation of how prevalent each level of understanding is within the sample. This quantitative perspective enhances the interpretive value of the table, making it an effective tool for visualising and analysing the results. By consolidating detailed responses into a concise format, the table provides a practical reference point for identifying areas where targeted educational or awareness initiatives may be most needed. It offers a clear link between the raw data and its

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VIII August 2025

implications, supporting further analysis and informed decision-making to strengthen knowledge of Circular Economy principles.

Description of Circular Economy Concept:

In the survey, a key question was posed to assess participants' grasp of the Circular Economy concept. They were invited to review a set of statements and choose the one they felt most accurately reflected its core principles. The resulting table offers a clear breakdown of how responses were distributed across the available options, showing both the number of respondents and the corresponding percentages for each. This structured presentation allows for quick comparison, highlighting which interpretations of the Circular Economy resonated most strongly with participants and revealing areas where further clarification or education may be needed. The detailed response distribution is as follows:

Table 2: Description of Circular Economy Concept

Option	Description of Circular Economy	Number of Participants	Percentage
(a)	A linear economic model focused on continuous growth and resource extraction	10	9.5%
(b)	An economic model that aims to minimise waste and keep resources in use for as long as possible	85	81.0%
(c)	An economic model that promotes unlimited consumption and resource depletion	5	4.8%
(d)	A business model that focuses on traditional manufacturing processes without considering environmental impacts	5	4.8%

The findings show that 81.0% of respondents accurately recognised the Circular Economy as an economic approach aimed at reducing waste and prolonging the use of resources. This reflects a solid grasp of its fundamental principles, particularly in relation to sustainability and efficient resource management. The table summarising these results presents a range of interpretations, with each response option representing a distinct perspective on the concept. The inclusion of percentage values adds clarity, illustrating the overall sentiment while revealing minority viewpoints. Together, these insights offer a well-rounded picture of participants' understanding of the Circular Economy and the extent to which its key ideas are being correctly interpreted.

Strategies and Practices of Circular Economy in Manufacturing:

When invited to share ideas on applying Circular Economy principles in the manufacturing sector, participants offered a diverse range of strategies, reflecting a strong awareness of sustainable production practices. A common theme was recycling, with many highlighting the reprocessing and repurposing of materials to extend their lifecycle and reduce dependence on new resource extraction. This aligns closely with the Circular Economy's goal of minimising waste and improving resource efficiency.

Product design for longevity was another frequently mentioned approach, focusing on creating durable, repairable, and upgradeable products to counter the short lifespan associated with linear economic models. Several participants also emphasised resource sharing, recognising that collaborative consumption can optimise utilisation and lower overall material demand.

Remanufacturing featured prominently in the responses, with participants noting the benefits of restoring used products to their original condition, thereby keeping materials in circulation for longer. Waste reduction strategies, aimed at minimising generation at every stage of production, were also acknowledged as essential for improving efficiency and lowering environmental impact.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VIII August 2025

Collectively, these responses highlight an informed understanding of how Circular Economy practices can be embedded into manufacturing operations. The strategies mentioned illustrate practical pathways for creating systems that are more sustainable, efficient, and resilient, while reinforcing the importance of raising awareness to accelerate the shift towards regenerative industrial models.

Data Analysis Result: Understanding of the Sustainable Development Goals (SDGs)

This section assessed participants' familiarity with the United Nations Sustainable Development Goals (SDGs) and their ability to correctly match selected goals with their corresponding descriptions. Beyond this recognition exercise, participants were also invited to share examples illustrating how manufacturing activities can support the achievement of one or more SDGs. These examples aimed to capture practical insights, linking sustainable manufacturing practices—such as energy-efficient production, responsible sourcing, waste reduction, and the adoption of clean technologies—to specific SDGs. The combined results provide a clearer picture of both the level of conceptual awareness among participants and their capacity to connect the goals to tangible actions within the manufacturing sector.

Familiarity with SDGs:

At the start of this section, participants were asked to self-assess their familiarity with the Sustainable Development Goals (SDGs), recognised as a global roadmap for advancing sustainability. The distribution of responses offers a concise snapshot of their awareness levels, reflecting how well these goals are understood within the surveyed population:

Table 3: Familiarity with SDGs

Option	Participants	Percentage
(a) Yes, I am familiar with all of the SDGs	45	42.9%
(b) Yes, I am familiar with some of the SDGs	50	47.6%
(c) No, I have no knowledge of the SDGs	10	9.5%

The data shows a varied awareness of the United Nations Sustainable Development Goals (SDGs) among respondents. A total of 42.9% reported being familiar with all SDGs, reflecting a strong grasp of the framework and its role in advancing global sustainability. Another 47.6% indicated awareness of only certain goals, suggesting partial but targeted knowledge in specific areas. The remaining 9.5% had no familiarity with the SDGs, pointing to an opportunity for focused awareness and educational initiatives. This spread illustrates a wide range of understanding, underscoring the need for continued efforts to broaden engagement and strengthen comprehension of the SDGs to support more effective contributions toward sustainable development.

Matching SDGs with Descriptions:

Next, participants were asked to match selected Sustainable Development Goals (SDGs) with their correct descriptions, an exercise designed to assess both their knowledge and their ability to connect each goal with its core purpose. The results of this activity demonstrated the extent to which participants could accurately interpret and align the goals with their intended focus, offering insight into their depth of understanding and familiarity with the SDG framework:

Table 4: Matching SDGs with Descriptions

SDG	Description	Participants	Percentage
i) SDG 7	(a) Affordable and Clean Energy	65	61.9%

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VIII August 2025

ii) SDG 12	(b) Responsible Consumption and Production	80	76.2%
iii) SDG 9	(c) Industry, Innovation, and Infrastructure	75	71.4%

The data indicates that participants demonstrated a strong ability to correctly match Sustainable Development Goals (SDGs) with their respective descriptions, reflecting a solid understanding of these global priorities. Specifically, 61.9% accurately identified SDG 7, Affordable and Clean Energy, highlighting awareness of the importance of accessible, sustainable energy. A higher proportion, 76.2%, correctly matched SDG 12, Responsible Consumption and Production, indicating recognition of the need for sustainable consumption patterns. For SDG 9, Industry, Innovation, and Infrastructure, 71.4% provided correct matches, underscoring their understanding of the role innovation and resilient infrastructure play in sustainable development. Collectively, these findings suggest participants possess a well-rounded comprehension of the SDGs assessed.

Examples of Manufacturing Practices and SDGs:

The final stage of the survey invited participants to share practical examples of how manufacturing practices could contribute to achieving the Sustainable Development Goals (SDGs). The open-ended responses revealed a range of forward-thinking and actionable ideas:

i. For SDG 7 (Affordable and Clean Energy), many emphasised the shift towards renewable energy in manufacturing operations, such as adopting solar and wind power. These approaches were recognised for their potential to lower carbon emissions and support the transition to clean energy sources.

ii. In relation to SDG 9 (Industry, Innovation, and Infrastructure), participants highlighted the importance of integrating technological advancements, automation, and modern infrastructure into manufacturing. Suggestions included the adoption of smart manufacturing systems and innovative production methods, reflecting an awareness of the role that industrial innovation plays in driving sustainable growth.

iii. For SDG 12 (Responsible Consumption and Production), the recurring focus was on applying circular economy strategies. Responses frequently mentioned designing products for durability, repairability, and recyclability, as well as reducing waste through resource-efficient processes. These practices were recognised as essential to reducing environmental impact and ensuring sustainable use of resources.

The results show that participants possess a clear understanding of how manufacturing practices align with the Sustainable Development Goals (SDGs). Their accurate matching of specific goals with their descriptions reflects not only solid theoretical knowledge but also an awareness of the practical links between industrial activities and global sustainability objectives. The responses highlight recognition of manufacturing's role in advancing areas such as clean energy access, responsible consumption, and the development of innovative, resilient infrastructure. This alignment demonstrates a holistic perspective, acknowledging that manufacturing can be a powerful driver of progress or a barrier to achieving a sustainable future, depending on the practices adopted.

Table 5: Framework for Integrating Circular Economy Principles with SDGs in the Manufacturing Industry

Framework Component	**Description**	**Aligned SDGs**	**Implementation Strategy**
1. Circular Economy Principles			
Resource Monitoring and Optimisation	Optimize use of materials and energy	SDG 12	Conduct thorough assessments to track and optimise the use of materials and energy, promoting the adoption of recycled and renewable inputs

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VIII August 2025

Product Lifecycle Extension	Design for durability, reparability, and recyclability	SDG 12	Focus on designing products for durability, repairability, and recyclability, using eco-friendly materials and modular design principles to extend product lifecycles
Waste Management and Circular Practices	Reduce, reuse, and recycle waste	SDG 12	Implement waste reduction strategies, establish recycling programs, encourage industrial symbiosis
Collaborative Supply Chains	Promote sharing, leasing, and reusing products	SDG 12	Develop partnerships to create circular supply chains and establish systems for resource sharing that reduce environmental impact
Remanufacturing and Product Restoration	Restore used products to their original condition	SDG 12	Invest in remanufacturing programmes and advanced technologies to restore products to their original condition, reducing demand for new raw materials
2. Technology and Innovation	Invest in R&D, implement energy-efficient technologies	SDG 7 and SDG 9	Commit to adopting innovative technologies, integrating renewable energy sources into operations, and fostering a culture of continuous improvement
3. Sustainable Product Design	Design for sustainability, use eco-friendly materials	SDG 12	Prioritise durability, repairability, and recyclability in product development, incorporate eco-friendly materials, and apply modular design principles to extend product lifecycles and ease component replacement
4. Resource Efficiency	Optimize resource use, create circular supply chains	SDG 12	Monitor and optimise material and energy use, integrate recycled and renewable resources, and foster partnerships that enable circular supply chains
5. Waste Management	Implement waste reduction and recycling programs	SDG 12	Implement waste reduction measures, establish effective recycling systems, and promote industrial symbiosis to reuse by-products across industries
6. Capacity Building and Engagement	Conduct training and engagement programs	SDG 12	Deliver training programmes to employees, involve stakeholders in sustainability initiatives, and share best practices to encourage widespread adoption
7. Performance Monitoring and Continuous Improvement	Develop metrics, track progress, review and assess strategies	SDG 12	Set measurable indicators, conduct regular reviews of strategies, and refine plans based on performance data and feedback to ensure sustained progress.

Aligned SDGs and Circular Economy Integration

SDG 7: Affordable and Clean Energy

Aims to ensure universal access to affordable, reliable, sustainable, and modern energy. Within a Circular Economy framework, this goal centres on improving energy efficiency, expanding the use of renewable energy

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VIII August 2025

sources, and cutting waste in energy consumption across manufacturing processes. Key actions include investing in high-efficiency technologies, incorporating renewable sources such as solar or wind power, and redesigning operations to reduce overall energy demand. These measures can lower energy costs, cut carbon emissions, and improve long-term energy security.

SDG 9: Industry, Innovation, and Infrastructure

Focuses on building resilient infrastructure, advancing inclusive and sustainable industrialisation, and fostering innovation. In the context of the Circular Economy, this involves promoting sustainable manufacturing methods, encouraging innovation in recycling and resource recovery, and developing adaptable infrastructure to support circular systems. Implementation can include funding research into sustainable materials, adopting closed-loop production methods, and upgrading infrastructure to accommodate circular supply chains. Expected benefits include higher resource efficiency, reduced environmental impacts, and expanded opportunities for green employment.

SDG 12: Responsible Consumption and Production

Seeks to establish sustainable consumption and production patterns. Integrating Circular Economy practices under this goal involves optimising material use, preventing waste, and extending product lifespans through reuse, refurbishment, and recycling. Actions include applying eco-design principles, raising consumer awareness about sustainable products, and implementing take-back programmes for end-of-life goods. Anticipated results include lower waste generation, decreased reliance on virgin resources, and a more sustainable consumption model within manufacturing.

This framework offers a structured approach for aligning Circular Economy principles with SDGs 7, 9, and 12 in the manufacturing sector, detailing targeted strategies and anticipated outcomes for each area. By mapping specific actions to these goals, it illustrates how manufacturing can directly contribute to affordable and clean energy, sustainable industrial growth, and responsible production and consumption. The framework underscores the interconnected nature of these objectives, showing how initiatives such as renewable energy adoption, closed-loop production, eco-design, and waste reduction complement one another to create systemic sustainability gains. It serves as a practical reference for industry stakeholders, guiding the integration of sustainable practices that support global targets while delivering economic, environmental, and social benefits.

Although the results highlight encouraging levels of recognition of SDGs and Circular Economy principles, they also reveal significant knowledge gaps. A notable share of participants reported either minimal or fragmented understanding, suggesting that current educational interventions have yet to cultivate deep, practice-oriented knowledge. This limitation is particularly important when considering the integration of CE and SDGs in manufacturing under Industry 4.0, which requires not only awareness but also technical capability and innovation-driven thinking. The findings align with studies in other ASEAN contexts that report similar gaps, pointing to the need for more hands-on, industry-partnered learning experiences. By acknowledging these shortcomings, the discussion maintains a balanced perspective: while ODL programmes are succeeding in raising baseline awareness, further steps are needed to translate knowledge into sustainable manufacturing practices. This reinforces the argument that educational institutions should act as enablers of industry readiness, bridging academic learning with practical industrial application.

CONCLUSION

The survey findings highlight a strong link between manufacturing resilience and the adoption of Circular Economy principles, reinforced by innovation and sustainability. Participants demonstrated a clear understanding of the Sustainable Development Goals (SDGs) and recognised the potential of sustainable manufacturing practices to drive transformation. Key strategies identified included the adoption of renewable energy, implementation of circular economy models, and integration of technological innovations, all seen as essential to strengthening industry resilience. By aligning processes with SDGs—particularly those related to responsible consumption and production—participants illustrated how sustainability can enhance environmental stewardship while fostering innovation. This alignment positions manufacturing to better

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VIII August 2025

withstand global challenges and adapt to changing demands. The ability of participants to correctly associate SDGs with their thematic areas further reflects their awareness of how sustainable approaches can reinforce industrial performance. Overall, the analysis underscores the importance of education, capacity building, and active engagement in advancing Circular Economy practices and innovation as pathways to a more resilient and sustainable manufacturing sector.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Open University Malaysia for providing the financial support that made this research possible. This contribution was essential in facilitating the successful execution and completion of the study.

REFERENCES

1. D. Aygün, I. G. Yılmaz, and Z. E. Sati, "Industry 4 Awareness: A Research on Postgraduate Students," in 6th International Management Information Systems Conference, Istanbul: Kadir Has University, 2019, pp. 239–247.
2. G. Brennan, M. Tennant, and F. Blomsma, "Business and production solutions: closing the loop," in Sustainability: Key Issues, H. Kopnina and E. Shoreman-Ouimet, Eds. London: EarthScan, Routledge, 2015, pp. 219–239.
3. European Commission, "Closing the Loop - an EU Action Plan for the Circular Economy," COM (2015) 614, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions, European Commission, Brussels, 2015.
4. Department of Statistics Malaysia, "Official Portal of Department of Statistics Malaysia," 2022. [Online]. Available: https://www.dosm.gov.my/. [Accessed: 11-May-2024].
5. D. Jati, Y. Hermawan, and M. A. Rahman, "Awareness and Knowledge Assessment of Sustainable Development Goals Among University Students," Jurnal Ekonomi & Studi Pembangunan, Oct. 2019.
6. P. Jones, M. Wynn, D. Hillier, and D. Comfort, "The Sustainable Development Goals and Information and Communication Technologies," Indonesian Journal of Sustainability Accounting and Management, vol. 1, no. 1, pp. 1–15, 2017. ISSN 2597-6214, e-ISSN 2597-6222.
7. J. Korhonen, A. Honkasalo, and J. Seppälä, "Circular economy: Critical examination and challenges for global sustainability," 2018.
8. S. Morton, D. Pencheon, and N. Squires, "Sustainable Development Goals (SDGs), and their implementation: A national global framework for health, development and equity needs a systems approach at every level," British Medical Bulletin, vol. 124, pp. 81–90, Oct. 2017.
9. A. Murray, K. R. Skene, and K. Haynes, "The interdisciplinary origins and application of the circular economy: Addressing its tensions and proposing a revised definition," 2017.
10. V. M. Piza, J. Aparicio, C. Rodríguez, R. Marín, J. Beltrán, and R. Bedolla, "Sustainability in Higher Education: A Didactic Strategy for Environmental Mainstreaming," Sustainability, vol. 10, p. 4556, 2018.
11. J. Sachs, The Age of Sustainable Development. New York: Columbia University Press, 2015.
12. S. Sikdar, "The novelty of the circular economy concept: Potential applications and limitations," 2019.
13. World Commission on Environment and Development, "Our common future," United Nations, 1987. [Online]. Available: https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf.
14. T. Zink and R. Geyer, "Circular economy rebound: A concept where circular economy activities might increase overall production, potentially offsetting environmental benefits," 2017.
15. L. Xu, "A review of classical and recent literature on circular economy: Proposing future research directions and highlighting unresolved theoretical foundations," 2014.