International Journal of Scientific Research and Modern Technology (IJSRMT) ijsrmt.com
Volume 5, Issue 10, 2026
DOI: https://doi.org/10.38124/ijsrmt.v5i10.1761

Effect of Green Product Design on the Sustainability of Solid Waste Social Enterprises in Nairobi City County, Kenya

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Publication Date: 2026/11/04

Abstract

- *Purpose:*
This study examines the relationship between green product design and the sustainability of solid waste social enterprises (SWSEs) in Nairobi City County, Kenya.

- *The Problem:*
Product innovation is often considered as the best strategic approach to to better waste management. Even so, SWSEs in Nairobi report mixed outcomes, and few studies have separated the contribution of green product design from that of other forms of product innovation when explaining economic, environmental, social and operational sustainability.

- *Method:*
A quantitative cross-sectional survey was conducted, with Resource-Based Theory as the guiding framework. Structured questionnaires were sent to 120 founders, managers, supervisors and technical staff in 30 SWSEs across Nairobi City County, and 108 were returned in usable form (a 90% response rate). Responses were analysed with frequencies, percentages, means and Pearson product-moment correlation.

- *Results:*
Respondents reported green product design mainly through minimising raw-material use (M = 4.69), followed by investment in eco-friendly research and development (M = 4.20), integration of environmental principles (M = 3.98) and environmental impact assessment (M = 3.75). On sustainability, social performance scored highest (M = 4.68), then environmental (M = 4.01) and operational efficiency (M = 3.33), while economic performance scored lowest (M = 2.67). Green product design correlated with sustainability more strongly ($r = 0.903$, $p < .001$) than eco-friendly packaging ($r = 0.194$, $p = .044$) or waste valorisation ($r = 0.121$, $p = .211$).

- *Recommendation:*
National and county governments should support environmentally responsible product design in SWSEs through innovation grants, suitable tax incentives and technical assistance.

Keywords: *Green Product Design, Sustainability, Solid Waste Social Enterprises, Resource-Based Theory, Nairobi City, Kenya.*

I. INTRODUCTION

Cities are increasingly growing, economies are expanding and consumption patterns are changing, and solid waste generation is rising worldwide as a result. More than two billion tonnes of waste are now produced globally each year. In low- and middle-income countries a large share of it is dumped in the open or burned, with serious consequences for the environment and public health. Open burning and dumping release greenhouse

Oyugi, B. O., Muiruri, D. Z., & Soko, D. J. (2026). Effect of Green Product Design on the Sustainability of Solid Waste Social Enterprises in Nairobi City County, Kenya. *International Journal of Scientific Research and Modern Technology*, *5*(10), 117–125. https://doi.org/10.38124/ijsrmt.v5i10.1761

gases, allow toxic leachate to seep into soil and water, and expose neighbouring communities to disease (Abubakar et al., 2022). The distance between the amount of waste generated and the amount managed safely is among the most pressing sustainability problems today, and narrowing it will require solutions fitted to local conditions, not uniform fixes.

The waste hierarchy and the circular economy now dominate policy and research debates. Both stress reducing, reusing, recycling and recovering resources ahead of disposal (Awino & Apitz, 2024; Monfared et al., 2025). Upcycling, eco-design and material recovery are central to this approach, and they are increasingly linked to progress on several Sustainable Development Goals (Monfared et al., 2025). These frameworks could make urban waste systems more resilient, yet their results depend largely on local institutional capacity and on how consistently they are applied.

Africa faces a version of the same problem. Waste generated per person remains lower than in wealthier regions, but fast urban population growth and shifting consumption are driving total volumes upward (Abubakar et al., 2022). African cities also receive goods and materials that richer regions regard as waste or low-value surplus, which adds pressure to systems already under strain. Across much of the continent, collection services are patchy, recycling infrastructure is thin and open dumping persists (Abubakar et al., 2022; Awino & Apitz, 2024).

Nairobi has much in common with Kampala and Dar es Salaam, where urban growth continues to outstrip waste infrastructure (Abubakar et al., 2022). A good deal of the waste produced in Nairobi is never collected, especially in informal settlements, and it ends up blocking drains, contributing to flooding and accumulating in public spaces (Abubakar et al., 2022). The Dandora dumpsite was officially declared full years ago, but it is still used every day because there is no official alternative place to take the waste.

SWSEs have emerged to fill part of this gap. They combine environmental, social and economic aims by bringing waste pickers into formal recycling and recovery chains and by transforming waste into products that can be sold (Ahen & Amankwah-Amoah, 2021). Green product design is one way these social enterprises can strengthen their sustainability. It means designing products to lower their environmental impact over the whole life cycle: choosing recycled or environmentally friendly materials, reducing material and energy use, limiting production waste, and building in durability, reusability, repairability and recyclability at end of life. The circular design literature separates strategies that slow resource loops, such as durability and repair, from those that close them through recovery and recycling (Bocken et al., 2016).

Most of the evidence on product innovation and sustainability, however, comes from manufacturing firms in developed economies, and solid waste social enterprises in African cities have received comparatively little attention (Monfared et al., 2025). For Nairobi, quantitative evidence on whether green product design affects SWSE sustainability, and by how much, is scarce. This study addresses that gap by examining the association between green product design and the sustainability of SWSEs in Nairobi City County.

➢ *Statement of the Problem*

Rapid urbanisation, population growth and changing consumption habits have increased solid waste generation across the world, with serious environmental, economic and social consequences. In cities like Nairobi, weak collection systems, low recycling rates, inefficient disposal and limited resource recovery obstruct sustainable waste management. Ideally, solid waste management would improve resource efficiency, reduce waste at source, protect the environment and return recovered materials to production as new products. In practice, persistent inefficiencies prevent this from happening.

In Nairobi City County the problem appears as uncollected waste, open dumping, blocked drains, pollution and continued dependence on sites such as Dandora (Abubakar et al., 2022). The National Solid Waste Management Strategy (2014) and the Sustainable Waste Management Act exist, but weak implementation and enforcement, limited financing and poor resource recovery continue to slow progress (Muheirwe et al., 2022).

SWSEs have become important actors in this setting because they pair waste management with social and economic objectives. Green product design offers them a means of lowering environmental impact, using resources more efficiently, turning recovered materials into new products, generating less waste and extracting more value from material that would otherwise be thrown away. Adopting it should help SWSEs perform better environmentally while also improving their financial stability and widening their social benefits.

Many SWSEs nevertheless find it hard to adopt innovative and environmentally sound product designs, and evidence on how far green product design contributes to their sustainability, particularly in Nairobi, is inadequate. Existing studies tend to treat waste management, recycling or product innovation broadly and do not examine how green product design relates specifically to the economic, environmental, social and operational sustainability of solid waste social enterprises (Farooq et al., 2022). This study responds to that gap in empirical understanding of the association between green product design and SWSE sustainability in Nairobi City County.

➢ *Research Objectives*

- To determine how widely green product design practices have been adopted by solid waste social enterprises in Nairobi City County.

- To assess the sustainability performance of these social enterprises on economic, environmental, social and operational dimensions.
- To examine the strength and significance of the relationship between green product design and the sustainability of solid waste social enterprises, compared with other product innovation dimensions (waste valorisation innovation and eco-friendly packaging innovation).

➢ *Research Questions and Hypothesis*

The first two objectives were addressed through two research questions:

- How widely are green product design practices adopted among solid waste social enterprises in Nairobi City County?
- How well do solid waste social enterprises perform on the economic, environmental, social and operational dimensions of sustainability?

The third objective was addressed through a formal hypothesis:

- H_0: Green product design has no statistically significant relationship with the sustainability of SWSEs in Nairobi City County.
- H_1: Green product design has a statistically significant relationship with the sustainability of SWSEs in Nairobi City County.

➢ *Theoretical Framework*

This study draws on Resource-Based Theory (RBT), which attributes sustained competitive advantage to resources and capabilities that are valuable, rare, difficult to imitate and difficult to substitute (Barney, 1991; Wernerfelt, 1984). Under RBT, performance differences between organisations arise not only from external market conditions but also from the way firms develop and use internal resources. For SWSEs, such resources include innovation capability, technical know-how, adaptive skills, social networks and operational processes, which together allow a social enterprise to turn waste into products with economic and social value. Hart (1995) carries the argument over to environmental capabilities, linking pollution prevention and product stewardship with possible competitive advantage.

SWSEs in Nairobi usually work with small budgets, poor infrastructure and restricted access to formal markets. Many still carry out recycling, composting, upcycling, eco-design and eco-friendly packaging, transforming waste streams into products and services that earn income and address environmental problems. Other studies support this view. Innovation capability has been found to improve environmental and financial performance, and smart waste technologies and digital tools have raised operational efficiency and sustainability outcomes in other settings (Farooq et al., 2022).

Green packaging and eco-design can also lower the environmental footprint of packaging in particular (Hussain et al., 2024). For social enterprises, innovation capability is important because it can produce economic, environmental and social value together. Soko et al. (2012) discuss management in terms of organisational effectiveness and human wellbeing, and Syengo et al. (2026), who study a different kind of organisation, identify leadership, governance, financial management, human capacity and stakeholder engagement as interacting conditions for lasting outcomes. Neither source provides direct evidence on green product design in Nairobi SWSEs, but both support the multidimensional view of sustainability adopted here. RBT provides a workable lens for the association examined in this study. It is only a lens, however, and does not test causation, given the limits of the design.

II. EMPIRICAL REVIEW

➢ *Product Innovation and the Sustainability of Solid Waste Social Enterprises*

Product innovation can help SWSEs make scarce materials go further and turn recovered resources into new products. How much this matters in Nairobi depends on the combination of technical capacity, market access and organisational resources. The circular economy literature separates waste reduction, retention of material value and closing of resource loops (Awino & Apitz, 2024; Kirchherr et al., 2023), and this study concentrates on green product design as one part of that broader picture. Reviews of sustainable product development show how design tools can be used to weigh environmental trade-offs before materials and production methods are settled (Ahmad et al., 2018).

Design decisions influence both the use of materials and what happens to a product at the end of its life, although this cross-sectional survey did not measure those downstream effects. Research on circular economy practices in the integrated waste sector provides useful background (Agyapong et al., 2025), and work on municipal waste systems shows that results depend on local infrastructure and disposal routes (Cheniti et al., 2024). Evidence at the level of social enterprises in Nairobi is therefore valuable in its own right, since findings from other sectors cannot simply be assumed to apply.

Eco-friendly packaging is related to green product design but is a separate form of innovation. Studies of sustainable packaging identify material and technological alternatives that can reduce packaging impacts (Hussain et al., 2024). Packaging is included in the comparative analysis to give the green product design correlation some context, not because the two are interchangeable.

Technology can also improve sorting, tracking and recovery, but the extent to which this potential is realised depends on finance, staff skills and everyday operating conditions (Farooq et al., 2022). That is another reason to treat product design separately from the wider innovation portfolio instead of attributing every sustainability gain to a single practice.

Social enterprises by definition pursue economic goals together with environmental and social ones. Jiatong et al. (2021) link social entrepreneurial factors and institutional conditions to the development of sustainable social enterprises, while Syengo et al. (2026), who examine faith-based organisations and not solid waste social enterprises, likewise point to the interaction of governance, financial capacity and organisational learning. Because the sectors differ, the findings cannot be compared directly, but they strengthen the argument for looking at more than one dimension of sustainability at a time.

Taken together, the literature justifies examining how product innovation relates to sustainability but leaves open how that relationship works among Nairobi's SWSEs. Much of the existing research concentrates on formal firms in other sectors and groups different types of innovation together. This study separates green product design from waste valorisation and packaging innovation and makes no claim that one causes the other.

➢ *Conceptual Framework*

Figure 1 shows green product design as the independent construct, measured through four questionnaire indicators, and sustainability as the dependent construct, measured on economic, environmental, social and operational dimensions. The arrows indicate a hypothesised association. The cross-sectional correlation reported below does not establish causation.

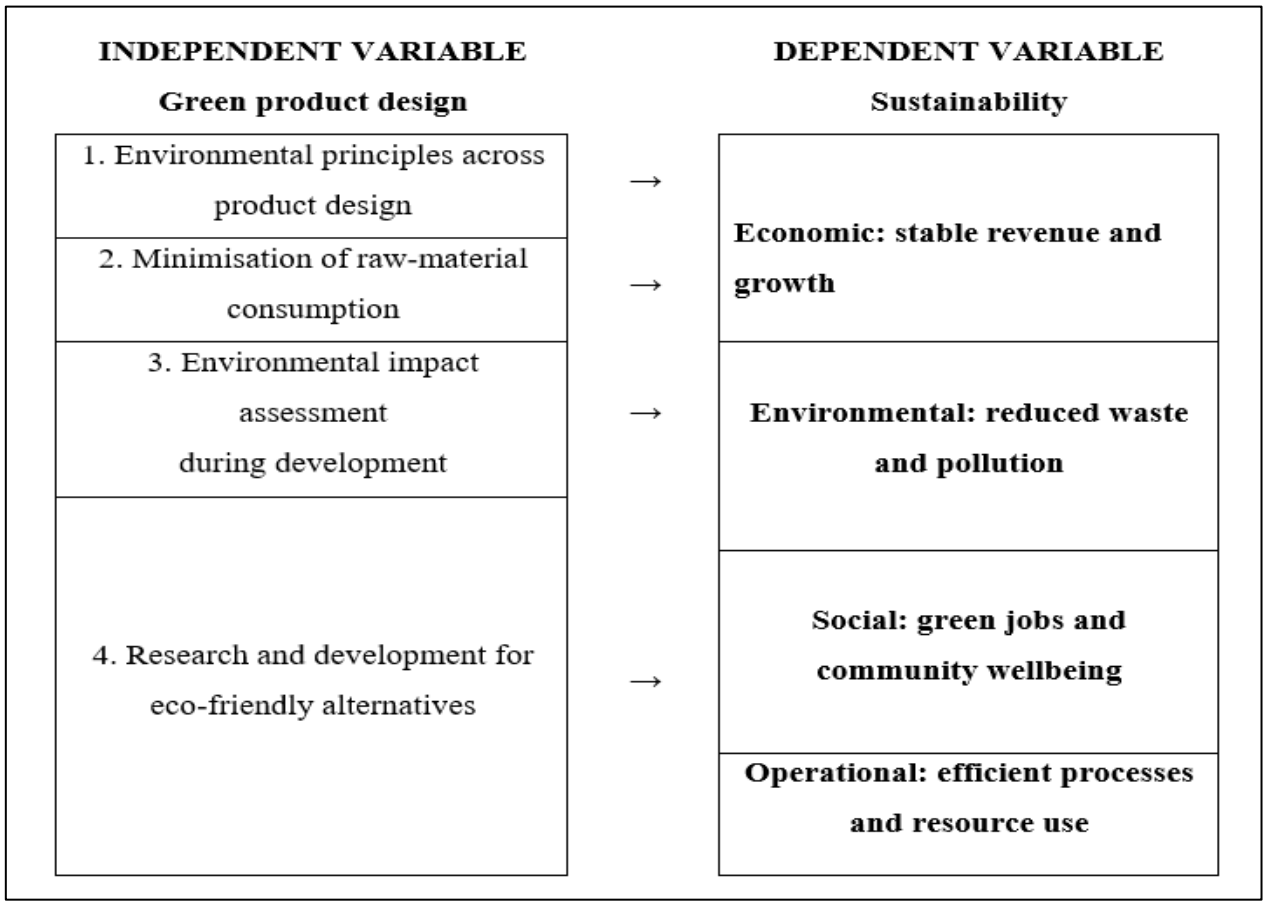


Fig 1 Conceptual Framework for the Association between Green Product Design and Sustainability.

The framework proposes an association between the overall green product design measure and the overall sustainability measure. The four indicators listed under each construct show how it was operationalised, and correlations between individual indicator pairs were not reported separately. Waste valorisation and eco-friendly packaging appear only in the comparative analysis that follows.

III. RESEARCH METHODOLOGY

➢ *Research Design*

The study adopted a quantitative cross-sectional design to examine the relationship between green product design and sustainability among SWSEs in Nairobi City County. Structured questionnaire data were collected over a defined period and analysed with descriptive statistics and Pearson correlation. Because the design captures associations at one point in time, it cannot establish the direction of influence or an independent causal effect.

➢ *Target Population, Sampling, and Sample Size*

The sampling frame consisted of 30 formally registered SWSEs that had operated in Nairobi City County for at least one year and were involved in product innovation. All 30 were included as a census. In each social enterprise, four founders, managers, supervisors or technical staff were purposively selected, giving 120 invited respondents. Of the 120 questionnaires distributed, 108 were usable, a response rate of 90%. Although the

census covers every enterprise in the frame, respondents within each esocial nterprise were purposively chosen, so responses from the same enterprise may not be fully independent.

➢ *Research Instrument, Validity, and Reliability*

Data were collected with structured questionnaires using five-point agreement items. Four items measured green product design (environmental principles, raw-material minimisation, impact assessment during development, and investment in eco-friendly research and development), and further items covered economic, environmental, social and operational sustainability. The parent study reports expert review for content validity, exploratory factor analysis for construct validity and a pilot test with 16 people from eight SWSEs that were excluded from the main sample. Overall reliability (Cronbach's alpha) was .80; construct-level coefficients and factor loadings are not reported in this manuscript. Life-cycle assessment can inform product development, but it needs evidence on material and process impacts that this questionnaire did not collect (Chang et al., 2014).

➢ *Data Collection Procedures*

Data collection lasted about eight weeks and began once ethical and administrative approval had been obtained from Tangaza University, the National Commission for Science, Technology and Innovation (NACOSTI permit number NACOSTI/P/26/4188444) and the relevant county and environmental authorities. Questionnaires were administered on paper and electronically through KoboToolbox to make participation easier. Participation was voluntary, and every respondent gave informed consent beforehand.

➢ *Data Analysis*

The data were first checked for completeness, consistency and missing values. Frequencies, percentages and means summarised what respondents reported about green product design and sustainability, and two-tailed Pearson correlations (N = 108) described the direction and strength of the associations, with $p < .05$ as the threshold for significance. Correlations for waste valorisation and eco-friendly packaging, taken from the wider study, are included for context. No regression, cluster adjustment or causal modelling was done. Because four respondents were sampled per enterprise and responses from the same enterprise may be correlated, the p-values should be read with caution, since treating clustered observations as independent can overstate the precision of conventional significance tests (Killip et al., 2004).

➢ *Ethical Considerations*

Tangaza University granted ethical clearance, and a research permit was obtained from NACOSTI in accordance with Kenya's research regulations. All respondents participated voluntarily after being told the purpose of the study and their right to withdraw at any time without consequence, and they gave informed consent. Identities and responses were kept confidential throughout.

IV. RESULTS AND DISCUSSION

➢ *Level of Adoption of Green Product Design Practices*

The first research question asked how far the surveyed SWSEs had adopted green product design practices. Respondents rated their agreement with four statements on a five-point scale: Strongly Disagree (SD), Disagree (D), Undecided (UD), Agree (A) and Strongly Agree (SA). Results are presented in Table 1.

Table 1 Green Product Design Practices Reported by Respondents

Statement	SD %	D %	UD %	A %	SA %	Mean
We integrate environmental principles into the design of our products from start to finish	1.9	1.9	18.5	51.9	25.9	3.98
Our products are designed specifically to minimise the consumption of raw materials	0.0	0.9	2.8	23.1	73.1	4.69
We systematically assess the environmental impact of products during their development	27.8	2.8	0.0	2.8	66.6	3.75
Our enterprise invests significantly in R&D for eco-friendly product alternatives	1.9	2.8	0.0	63.9	31.4	4.20

Note. SD = Strongly Disagree; D = Disagree; UD = Undecided; A = Agree; SA = Strongly Agree. Percentages and Means are Based on 108 Usable Questionnaires. Field Data, 2026.

Overall, the surveyed SWSEs reported a high level of adoption of green product design. For the integration of environmental principles into design from start to finish, 77.8% of respondents agreed or strongly agreed, 18.5% were undecided and only 3.8% disagreed (M = 3.98). This suggests that environmental thinking runs through product development in most of these enterprises and is not added at the end. Viewed through Resource-Based Theory, the result is consistent with environmentally embedded design becoming an internal organisational capability, although these cross-sectional data cannot show whether enterprises with this capability perform better than those without it (Barney, 1991).

On designing products to minimise raw-material use, 73.1% of respondents strongly agreed, 2.8% were undecided and 0.9% disagreed. This item had the highest mean of the four (M = 4.69), which makes raw-material minimisation the most widely and most strongly adopted practice in the sample. The result agrees with the economic argument for green product design in the literature: depending less on virgin raw materials tends to reduce input costs, protect enterprises against price swings and

open up revenue from recovered and secondary materials. Circular design research treats material reduction as a plausible efficiency mechanism, although this study did not measure input costs or realised savings (Bocken et al., 2016).

Impact assessment during product development produced a different picture. Here 66.6% strongly agreed but 27.8% strongly disagreed, a sharply divided response. The item had the lowest mean (M = 3.75), and the split suggests that adoption varies across enterprises, although the survey cannot show which ones have a formal assessment process. Earlier work on life-cycle assessment explains why systematic evaluation during development is more demanding than an informal commitment to environmental principles (Chang et al., 2014).

On research and development, 63.9% agreed and 31.4% strongly agreed that their enterprise invests in eco-friendly alternatives (M = 4.20, the second-highest mean). Overall, respondents reported the strongest practices in raw-material minimisation and R&D, with integration of environmental principles and systematic impact assessment somewhat behind. These remain self-reported responses and not independently verified measures of enterprise investment. The fairly high R&D rating points to interest in alternatives, but self-reported investment says nothing about technical feasibility or product performance, and reviews of sustainable design recommend assessing such trade-offs explicitly (Ahmad et al., 2018).

The pattern fits the view that material efficiency and design capability can serve as valuable enterprise resources (Barney, 1991; Wernerfelt, 1984), and circular economy research gives reasonable grounds for considering product design and material recovery together (Awino & Apitz, 2024; Kirchherr et al., 2023). Even so, the results describe reported practice and do not show that any of the four practices caused a particular sustainability outcome.

- *Sustainability Performance of Solid Waste Social Enterprises*

The second research question concerned sustainability performance on four dimensions: economic, environmental, social and operational. Table 2 presents the mean scores.

Table 2 Sustainability Performance Reported by Respondents

Sustainability Dimension and Indicator	Mean	Interpretation
Economic: stable revenue and business growth	2.67	Weakest performance
Environmental: reduced waste generation and pollution	4.01	High performance
Social: green jobs and improved community wellbeing	4.68	Highest performance
Operational: efficient processes with minimal resource waste	3.33	Moderate performance

Note. Means are Based on 108 Usable Questionnaires Using a Five-Point Agreement Scale. These Indicators Reflect Respondents' Self-Reported Perceptions of Enterprise Performance. Field Data, 2026.

Performance was uneven across the dimensions. Social sustainability was strongest (M = 4.68), with 80.6% of respondents strongly agreeing and a further 11.1% agreeing that their enterprise had created green jobs and improved community wellbeing. Environmental sustainability was also high (M = 4.01), and 84.2% agreed or strongly agreed that operations had reduced waste and pollution. Operational sustainability was in the middle (M = 3.33). Economic sustainability was clearly the weakest dimension (M = 2.67), with 57.4% of respondents disagreeing or strongly disagreeing that product innovation had produced stable revenue or business growth. The enterprises thus appear to deliver clearer social and environmental benefits than financial ones, which raises a question about how sustainable green product design is as a strategy if economic returns do not eventually follow. The social result should not be taken as evidence that green jobs are secure or well paid; Barford and Ahmad (2021) document continuing precarity among waste pickers in recycled-plastics supply chains, including in Nairobi. Strong social and environmental scores also do not guarantee adequate cash flow, since research on circular business models identifies organisational, market and value-chain barriers to capturing economic value (Guldmann & Huulgaard, 2020; Sarja et al., 2021).

- *Relationship Between Green Product Design and Sustainability*

The third objective examined how strongly and how significantly green product design relates to sustainability, compared with two other product innovation dimensions from the wider study: waste valorisation innovation and eco-friendly packaging innovation. Pearson's product-moment correlation was used to test the hypothesis, and the results are shown in Table 3.

Table 3 Pearson Correlations of Product Innovation Dimensions with Sustainability

Product Innovation Dimension	Pearson r with Sustainability	p-Value (2-Tailed)	Decision
Green product design	0.903**	< .001	Significant, positive
Waste valorisation innovation	0.121	.211	Not significant
Eco-friendly packaging innovation	0.194*	.044	Significant, positive

*Note. N = 108 Respondent Questionnaires. Two-Tailed Tests. *p < .05. **p < .01. Correlations do not Account for Within-Enterprise Clustering. Field Data, 2026.*

Green product design had a very strong, positive and statistically significant correlation with sustainability ($r = 0.903$, $p < .001$). Eco-friendly packaging innovation showed a weak but significant correlation ($r = 0.194$, $p = .044$), and waste valorisation innovation a weak, non-significant one ($r = 0.121$, $p = .211$). On this evidence the null hypothesis, that green product design has no significant relationship with SWSE sustainability, is rejected in favour of the alternative. Green product design is significantly related to sustainability and is clearly the strongest of the three innovation dimensions examined. The weaker associations for packaging and valorisation reflect this sample of respondents and should not be taken to mean that these practices have no environmental value. Circular product strategies may depend on complementary business models and recovery systems (Bocken et al., 2016).

Green product design and sustainability share roughly 81.5% of their respondent-level variance ($r^2 \approx .815$). This figure describes the overlap between the two measured scores; it does not mean that green design "caused" 81.5% of sustainability. Common survey methods, possible conceptual overlap between the two constructs and the clustering of responses within enterprises may all inflate the estimate to some extent. Through the lens of Resource-Based Theory the association is compatible with a capability-based explanation, but a cross-sectional design cannot test that mechanism or isolate an independent effect. Common-method bias is a recognised concern when the same respondents report predictors and outcomes on the same instrument (Podsakoff et al., 2003). Responses are also nested within 30 enterprises, and an intracluster correlation with a cluster-aware sensitivity analysis would help show how robust the reported significance levels are (Killip et al., 2004).

Of the three innovation dimensions examined, green product design had by far the largest bivariate correlation with sustainability. The separate correlations, however, do not by themselves show that the differences between them are statistically significant, and they do not isolate the unique contribution of green product design once the other dimensions are controlled. The distinction matters because obstacles to circular business model innovation can arise at the enterprise, value-chain and market levels even where a design practice has been adopted (Guldmann & Huulgaard, 2020).

V. CONCLUSION

This study found a strong association between green product design and the sustainability of solid waste social enterprises in Nairobi City County. Among the design practices, minimising raw-material consumption scored highest ($M = 4.69$), followed by investment in eco-friendly research and development ($M = 4.20$), integration of environmental principles ($M = 3.98$) and systematic environmental impact assessment ($M = 3.75$). Among the sustainability dimensions, social sustainability scored highest ($M = 4.68$), followed by environmental ($M = 4.01$), operational ($M = 3.33$) and economic sustainability ($M = 2.67$).

The correlations support this picture. Green product design had the strongest significant relationship with sustainability ($r = 0.903$, $p < .001$), eco-friendly packaging had a weak but significant one ($r = 0.194$, $p = .044$), and waste valorisation was not significantly correlated with sustainability ($r = 0.121$, $p = .211$). In this sample, green product design is the clearest bivariate correlate of sustainability among the innovation dimensions studied, although the enterprises' weak economic performance suggests that their social and environmental gains have not yet become comparable financial returns. One interpretation is that environmental capability may be valuable without guaranteeing a short-term financial return, which is in line with the distinction between potential advantage and realised outcomes in the natural-resource-based view (Hart, 1995).

RECOMMENDATIONS

- National and county governments should strengthen policies that support green product innovation among SWSEs through innovation grants, tax incentives, technical support and access to suitable technology.
- SWSEs should invest in environmentally sustainable product design that reduces waste, improves resource efficiency and strengthens market competitiveness, while giving priority to strategies that convert their environmental and social gains into stronger and more stable economic returns.
- Government agencies, private-sector actors, research institutions and social enterprises should strengthen partnerships for knowledge sharing, technology development and access to finance, so that green product innovation can be scaled up.

Future research should use enterprise-level or multilevel analysis with clearly reported construct scores and reliability coefficients, together with longitudinal or intervention designs where feasible, and should consider separate outcome models to test whether the relationship differs across the economic, environmental, social and operational dimensions of sustainability. Future studies should also use independently observed material flows and revenue data, assess job quality as well as job numbers, and examine the business-model conditions under which circular product designs produce durable income (Barford & Ahmad, 2021; Sarja et al., 2021).

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