



A "Lightweight" Digital End-of-Life (EoL) Passport via QR Code for Power Banks: Comparing Short vs Long vs Map-Enabled Pages on Drop-off Behavior

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Abstract

This study examines the effectiveness of a lightweight digital End-of-Life (EoL) passport, accessed via QR code, in promoting proper disposal behavior for used power banks. The growing use of portable electronic devices has intensified concerns regarding the end-of-life management of small battery-containing products, particularly because improper disposal of power banks can generate environmental hazards, safety risks, and loss of recoverable materials. Although designated collection and recycling channels are increasingly available, consumer participation in formal drop-off systems remains limited. In response, this research investigates whether the design of a QR-linked digital EoL passport can influence users' disposal intentions and behaviors. Three interface conditions were developed and compared: a Short Page presenting concise disposal guidance, a Long Page offering more extensive information on environmental impact and recycling processes, and a Map-Enabled Page integrating location-based support for nearby drop-off points. A controlled experimental study was conducted with 30 participants, equally assigned to the three conditions. The study assessed drop-off intention, perceived convenience, information sufficiency, system usability, perceived usefulness, and actual drop-off completion. The findings indicate that the Map-Enabled Page achieved the strongest overall performance, particularly in perceived convenience, usability, and verified drop-off completion, while the Long Page yielded the highest information sufficiency scores. These results suggest that interface designs which reduce practical barriers to action may be more effective in encouraging responsible end-of-life behavior than designs that focus primarily on increasing informational depth. The study contributes to the emerging literature on sustainable human-computer interaction, digital product stewardship, and e-waste management by demonstrating the value of lightweight, action-oriented digital interventions for consumer electronics disposal.

Keywords: digital End-of-Life passport, QR code, power bank disposal, e-waste management, drop-off behavior, consumer behavior

INTRODUCTION



The proliferation of portable electronic devices, particularly power banks, has created a significant end-of-life (EoL) management challenge. With approximately 62 million tonnes of Waste Electrical and Electronic Equipment (WEEE) generated globally in 2022 (Paolucci et al., 2025), innovative solutions are urgently needed to improve consumer participation in take-back programs. Digital End-of-Life (EoL) Passport is playing vital role in environmental awareness to persuade consumer learn how to eliminate electrical devices correctly. Thus, Digital End-of-Life (EoL) Passport accessed via QR codes represents a promising technological intervention, yet critical questions remain about optimal information design and interface features.

The rapid growth of portable electronic devices has led to a significant increase in the use of power banks as an everyday convenience product. Power banks support mobile lifestyles by enabling users to recharge smartphones, tablets, and other digital devices while away from fixed power sources. However, as their adoption expands, so does the challenge of managing them at the end of their useful life. Because power banks contain lithium-ion batteries and electronic components, improper disposal can create environmental pollution, fire hazards, and loss of valuable recoverable materials. Effective end-of-life (EoL) management of these products is therefore increasingly important for both environmental sustainability and public safety.

Despite the availability of recycling or drop-off channels in many areas, consumer participation in proper disposal systems remains limited. Many users are uncertain about how, where, and when to dispose of used power banks safely. Some may keep unused or damaged units at home, while others may discard them with general household waste due to lack of awareness, inconvenience, or insufficient guidance. This gap between available disposal infrastructure and actual user behavior highlights the need for communication tools that are simple, timely, and easy to access at the point of decision-making.

One promising approach is the use of a digital End-of-Life passport linked to a product through a QR code. In this context, an EoL passport refers to a lightweight digital information page that provides users with disposal-related guidance, such as safety instructions, environmental information, and drop-off options. Compared with traditional printed labels or manuals, a QR-code-based solution can deliver more flexible and up-to-date information while requiring minimal physical space on the product or packaging. It also offers an opportunity to tailor the amount and format of information presented to users, potentially influencing whether they take appropriate disposal action.

Simply providing digital information does not always lead to behavioral change. The design of an End-of-Life (EoL) page may influence how users respond to used power banks. A short page may reduce cognitive load and communicate the key disposal action quickly. A longer page may improve understanding by providing more details about environmental impact, safety risks, and disposal procedures. A map-enabled page may further reduce user effort by helping users locate nearby drop-off points. These three designs represent different assumptions about what encourages proper disposal behavior: simplicity, information depth, and actionability.



Although previous studies have discussed e-waste management, digital product passports, QR-code-based information systems, and location-based recycling support, limited research has empirically examined how different designs of a consumer-facing EoL passport influence actual disposal behavior. In particular, there is still a lack of comparative evidence on whether users respond better to concise information, detailed explanatory content, or location-enabled support when deciding to drop off small battery-containing products such as power banks. Therefore, this study addresses this gap by comparing short, long, and map-enabled QR-linked EoL passport pages and evaluating their effects on drop-off intention and behavior. This study compares three versions of a lightweight digital EoL passport for power banks: a short page, a long page, and a map-enabled page. The main objective is to examine whether these page designs affect users' drop-off intention or actual drop-off behavior. Rather than viewing disposal only as a waste-management issue, this study considers it a user behavior problem shaped by interface design, information accessibility, and perceived effort.

The topic is relevant to circular economy practices and digital product stewardship, where producers are increasingly encouraged to support product traceability, reuse, repair, and responsible disposal. Power banks are an appropriate case because they are widely used, portable, and contain batteries, yet they are often overlooked in household disposal practices.

Therefore, this research aims to identify which QR-linked EoL passport design most effectively supports proper disposal action. By comparing short, long, and map-enabled pages, the findings may contribute to sustainable human-computer interaction, digital nudging, and e-waste management, while also offering practical guidance for designing low-cost digital interventions for consumer electronics.

OBJECTIVE

To compare the effectiveness of three digital EoL passport designs (Short Page, Long Page, Map-Enabled Page) on consumer intention to drop off power banks at designated collection points.

LITERATURE REVIEW

The global proliferation of electronic devices has precipitated an unprecedented environmental challenge: the exponential growth of electronic waste (e-waste), now recognized as the world's fastest-growing waste stream (Paolucci et al., 2025). As portable electronics have become ubiquitous in modern life, the volume of discarded electrical and electronic equipment continues to escalate at alarming rates, with particularly concerning implications for small consumer electronics such as power banks. These portable battery devices, powered predominantly by lithium-ion battery technology, have experienced explosive market growth driven by the increasing energy demands of smartphones, tablets, and other mobile devices. However, this proliferation carries significant environmental and public health consequences when these products reach their end-of-life (EoL) stage.

Electronic waste represents one of the fastest-growing waste streams globally, with WEEE generation reaching approximately 62 million tonnes in 2022 and continuing to increase (Paolucci et al., 2025). Portable



electronics, including power banks, present unique challenges due to their lithium-ion battery content, which poses environmental and safety risks when improperly disposed (Munonye et al., 2025). Despite regulatory frameworks such as Extended Producer Responsibility (EPR) schemes, consumer participation in formal take-back programs remains disappointingly low (Andersen et al., 2023).

Power banks exemplify the "small electronics" problem: they are ubiquitous, frequently replaced, easily discarded in household waste, and contain valuable materials that could be recovered through proper recycling. Current collection rates for small electronics are significantly lower than for larger appliances, partly due to consumer inconvenience, lack of awareness about proper disposal methods, and insufficient motivation to participate in take-back programs.

Power banks and similar lithium-ion battery-containing devices pose unique challenges within the broader e-waste landscape. The improper disposal of these products introduces toxic materials—including lithium, cobalt, nickel, and other heavy metals—into landfills and incinerators, where they can leach into soil and groundwater or release hazardous emissions (Başal et al., 2024). Research has documented that lithium-ion batteries from consumer electronics represent a growing fraction of hazardous waste streams, with collection rates remaining critically low despite their environmental risks. In Malaysia, surveys reveal that the majority of spent lithium-ion batteries are either stored at home indefinitely or disposed of improperly through municipal waste channels. This pattern of consumer behavior is replicated across both developed and developing nations (Munonye et al., 2025) , (Andersen et al., 2023). Power banks also contain valuable materials—lithium, cobalt, copper—recoverable through proper recycling, representing a significant lost resource opportunity. As global demand for lithium-ion batteries continues to surge, the imperative to establish effective EoL management systems has never been more urgent (Henten et al., 2025).

Consumer-Facing Applications

A smaller body of work has explored consumer-facing DPP applications. Proposed a user-centric e-waste management system utilizing a web portal and QR code scanning to trace component recycling journeys, providing consumers with a seamless interface for accessing product details. Hagedorn et al. developed an "application-friendly tool" for e-waste decision support, emphasizing the need for DPPs to guide consumer choices through transparent information exchange.

Başal et al. (2024) reviewed DPPs in marketing contexts, noting that they provide online and offline access to product information via QR codes and web links, facilitating reuse, repair, and recycling processes (Başal et al., 2024). They emphasize that DPPs aim to drive more responsible purchasing and disposal choices by visualizing environmental performance. However, their analysis is conceptual rather than empirical, lacking behavioral validation.

A critical limitation across these studies is the absence of controlled evaluation of consumer responses to different DPP designs. While technical feasibility is demonstrated, questions about optimal information presentation, user engagement, and behavioral effectiveness remain unanswered.

3.2 QR Codes as Access Points



QR codes serve as the primary interface between physical products and digital information in most DPP implementations. Bashir (2022). explored leveraging QR codes to communicate sustainability-related product information, touching on consumer awareness and circular economy concepts (Bashir, 2022). Korshunova et al. (2025) described a regional e-waste management system where each item is marked with a QR code indicating funds to be returned, though they provided limited effectiveness data (Korshunova et al., 2025).

The Rubbin app, developed by Rimbawa et al. (2024) utilizes QR code recognition to streamline transaction processes between waste generators and collectors, demonstrating practical application in household waste management (Rimbawa et al., 2024). Their system reported positive changes in community waste management habits, though the specific contribution of QR functionality versus other features (e.g., Google Maps integration) was not isolated.

These applications demonstrate that QR codes are technically viable and increasingly familiar to consumers. However, the literature lacks systematic investigation of what information should be presented after a QR scan to maximize behavioral impact.

Consumer Behavior in E-Waste

Understanding the drivers and barriers of consumer participation in e-waste programs is essential for designing effective interventions. Convenience consistently emerges as a primary determinant of recycling behavior. Umar et al. (2025) conducted a field trial of the E-Trash location-based waste reporting application, finding that it effectively enhanced citizen participation and improved sanitation personnel response efficiency (Umar et al., 2025). The system demonstrated optimal functionality across diverse network conditions and yielded reduced illegal waste accumulation, primarily due to bidirectional notification systems that reduced uncertainty and effort.

Ambrosio et al. (2022) developed a "Recycling as a Service" mobile application that connects waste generators with collectors via Google Maps (Ambrosio et al., 2022). By allowing users to set collection details (location, time, amount) and enabling collectors to visualize and book nearby requests, the system eliminated the need for hardware-equipped bins and reduced logistical barriers. This model demonstrates that reducing friction in the recycling process can significantly enhance participation.

Lloren (2023). designed a mobile app for solid waste collection in the Philippines employing GPS-directed truck systems for real-time tracking (Lloren, 2023). The study found high community engagement and interest, indicating that digital systems with real-time tracking and community involvement can improve waste management effectiveness.

Moreover, Guo et al. (2023) investigated consumer willingness to recycle wasted batteries of electric vehicles, finding that intentions are strongly and positively affected by perceptions of government policy and environmental attitudes (Guo et al., 2023). Perceived benefits mediate intentions while perceived losses reduce them, suggesting that framing and messaging are critical.



Veleva et al. (2018) examined emerging drivers for equipment reuse and remanufacturing in the biotech industry, identifying policy signals and corporate sustainability commitments as key motivators (Veleva et al., 2018). Their findings suggest that regulatory context and institutional support shape individual behavior. These studies indicate that DPP systems operate within broader policy and attitudinal contexts. Design interventions must account for varying levels of environmental motivation and policy awareness among users.

METHODOLOGY

This research will develop and evaluate three distinct "lightweight" digital EoL passport designs for power banks, accessed via QR codes affixed to product packaging or the devices themselves. All three conditions will share a common technical infrastructure while varying in information presentation and interface features.

Common Technical Infrastructure

All three conditions will utilize:

- QR Code Generation: Unique QR codes will be generated for each power bank unit using a standardized encoding scheme (QR Code Model 2, Error Correction Level M) to ensure reliable scanning across diverse smartphone cameras and lighting conditions.
 - Mobile-Optimized Web Application: The QR codes will link to a responsive web application optimized for mobile browsers, eliminating the need for app downloads and reducing barriers to access.
 - Backend Tracking System: A secure backend database will log all QR scans, recording timestamp, device ID (anonymized), and subsequent user actions (page views, button clicks, drop-off completion).
 - Drop-Off Verification: Participants will be instructed to scan a second QR code at the collection point to verify drop-off completion, enabling objective behavioral measurement.
 - Privacy Protection: All data collection will comply with GDPR and institutional ethics requirements, with user consent obtained before participation and data anonymization protocols implemented.
 - Condition 1: Short Page Design
 - The Short Page condition provides minimal, essential information focused on actionable guidance.
 - Content Elements:
 1. Headline: "Recycle Your Power Bank Safely"
 2. Key Message (2-3 sentences): Brief explanation of why proper disposal is important (battery hazards, material recovery)
 3. Action Instruction: "Find your nearest drop-off point below"
 4. Drop-Off Location List: Text list of 3-5 nearest collection points with names and addresses
 5. Call-to-Action Button: "I've Dropped It Off" (links to verification QR scan)
- Design Principles:
- Minimalist visual design with ample white space



- Large, readable fonts (minimum 16px body text)
- Single-column layout requiring minimal scrolling
- Estimated reading time: 30-45 seconds
- Total word count: approximately 100-150 words

Rationale: This condition tests whether reducing cognitive load and providing clear, actionable guidance maximizes behavioral response. It aligns with "friction reduction" principles identified in successful field trials (Umar et al., 2025) , (Thaler & Sunstein, 2008).

Condition 2: Long Page Design

The Long Page condition provides comprehensive information about power bank recycling, environmental impacts, and the circular economy.

Content Elements:

1. Headline: "Recycle Your Power Bank Safely"
2. Extended Introduction (1-2 paragraphs): Detailed explanation of e-waste challenges, battery hazards, and environmental benefits of recycling
3. Recycling Process Section: Description of what happens to power banks after drop-off, including disassembly, material recovery, and reuse pathways
4. Environmental Impact Data: Statistics on material recovery rates, CO2 emissions avoided, and resource conservation
5. Circular Economy Context: Explanation of how recycling contributes to circular economy goals
6. Safety Information: Detailed guidance on safe handling and transportation
7. Drop-Off Location List: Text list of 3-5 nearest collection points with names and addresses
8. FAQ Section: Answers to common questions about recycling eligibility, preparation, and incentives
9. Call-to-Action Button: "I've Dropped It Off" (links to verification QR scan)

Design Principles:

- Multi-section layout with clear headings
- Infographics and icons to illustrate key concepts
- Collapsible sections to manage page length
- Estimated reading time: 3-5 minutes
- Total word count: approximately 600-800 words

Rationale: This condition tests whether comprehensive information increases motivation and commitment through enhanced awareness and understanding. It aligns with information-based intervention approaches common in environmental education (Başal et al., 2024) , (Bashir, 2022).

Condition 3: Map-Enabled Page Design

The Map-Enabled Page condition integrates location-based services and interactive mapping functionality.

Content Elements:

1. Headline: "Recycle Your Power Bank Safely"



2. Key Message (2-3 sentences): Brief explanation of why proper disposal is important (similar to Short Page)

3. Interactive Map: Embedded map (Google Maps API or OpenStreetMap) displaying:

- User's current location (with permission)
- Nearby drop-off points marked with custom icons
- Distance indicators for each location
- Clustering for areas with multiple collection points

4. Location Cards: Below the map, expandable cards for each nearby location showing:

- Name and address
- Distance from user
- Operating hours
- "Get Directions" button (opens navigation app)
- Photo of the collection point (if available)

5. Filter Options: Ability to filter by collection point type (retail, municipal, specialized)

6. Call-to-Action Button: "I've Dropped It Off" (links to verification QR scan)

Design Principles:

- Map occupies prominent position (50-60% of initial viewport)
- Interactive elements (zoom, pan, marker selection)
- Seamless integration with device navigation apps
- Estimated interaction time: 1-2 minutes
- Total word count: approximately 150-200 words (excluding map interface)

Rationale: This condition tests whether location-based features and visual spatial information provide additional behavioral benefits beyond textual information. It builds on successful LBS implementations (Umar et al., 2025) , (Ambrosio et al., 2022) , (Rimbawa et al., 2024) while isolating the specific contribution of map functionality.

4.2 Quality Assurance and Pilot Testing

Before the main study, all three conditions will undergo;

1. Usability Testing: 10-15 participants per condition will complete think-aloud protocols to identify usability issues

2. Technical Testing: Cross-device and cross-browser compatibility testing

3. Load Testing: Server capacity testing to ensure stability under concurrent user load

4. Pilot Study: Small-scale pilot (n=30 per condition) to validate measures and procedures

Measurement Instruments



Baseline Survey (administered at enrollment):

1. Demographics: Age, gender, education level, employment status
2. Prior Recycling Behavior: Frequency of electronics recycling, familiarity with collection points
3. Environmental Motivation: New Ecological Paradigm (NEP) Scale (Dunlap, Van Liere, Mertig, & Jones, 2000). (15 items, 5-point Likert scale)
4. Technology Proficiency: Self-reported comfort with smartphone apps and QR codes
5. Power Bank Ownership: Current ownership, replacement frequency, prior disposal methods

Immediate Post-Scan Survey (administered immediately after QR scan):

1. Drop-Off Intention: "How likely are you to drop off this power bank at a collection point within the next week?" (7-point scale: 1 = Very unlikely, 7 = Very likely)
2. Perceived Convenience: "How convenient would it be for you to drop off this power bank?" (7-point scale: 1 = Very inconvenient, 7 = Very convenient)
3. Information Sufficiency: "The information provided was sufficient to help me decide what to do" (7-point agreement scale)
4. User Experience: System Usability Scale (SUS) (Brooke, 1996). (10 items, 5-point agreement scale)
5. Perceived Usefulness: "This system would be useful for helping me recycle electronics" (7-point agreement scale)
6. Attitudes Toward DPPs: 3 items assessing favorability toward digital product passport systems (7-point scale)

Follow-Up Survey (administered 2 weeks after initial scan, regardless of drop-off completion):

1. Drop-Off Completion: "Did you drop off the power bank at a collection point?" (Yes/No, verified against QR scan data)
2. Barriers Experienced: Open-ended question about obstacles encountered
3. Suggestions for Improvement: Open-ended question about desired features or changes
4. Future Intentions: "How likely are you to use similar systems in the future?" (7-point scale)

4.4 Data Analysis Plan

Quantitative analysis will be used to investigate the effects of different lightweight digital End-of-Life (EoL) passport designs—specifically short, long, and map-enabled pages—on users' drop-off behavior. This method enables the researcher to compare the effectiveness of each page type using measurable behavioral data. By analyzing differences across conditions, the study can determine whether page design significantly influences users' willingness or ability to dispose of used power banks through proper drop-off channels. The results will help reveal which information format is most effective in supporting environmentally responsible end-of-life behavior.

This study employed a purposive sampling technique to select participants who were relevant to the research context. The target participants were users who had experience using power banks or portable electronic devices, as they were more likely to understand the issue of power bank disposal and interact



meaningfully with the QR-linked End-of-Life (EoL) passport. A total of 30 participants were selected and equally assigned to three experimental conditions: Short Page, Long Page, and Map-Enabled Page, with 10 participants in each group. This balanced allocation allowed the study to compare user responses across the three EoL passport designs in terms of drop-off intention, perceived convenience, information sufficiency, usability, and actual drop-off behavior.

RESULT

This research proposal presents a controlled experimental study to evaluate three distinct "lightweight" digital EoL passport designs for power banks: (1) a Short Page condition providing minimal, essential information; (2) a Long Page condition offering comprehensive lifecycle and recycling information; and (3) a Map-Enabled Page condition integrating location-based services to display nearby drop-off points. The study will measure their comparative effects on consumer drop-off intention, completion rates, and actual take-back behavior. A total of 30 participants took part in the study, with 10 participants assigned to each condition: Short Page, Long Page, and Map-Enabled Page. The purpose of the analysis was to compare how different lightweight digital End-of-Life (EoL) passport page designs influenced users' drop-off intention, perceived convenience, information sufficiency, system usability, and actual drop-off behavior for used power banks.

Participant Distribution

The 30 participants were evenly distributed across the three experimental conditions:

- Short Page: 10 participants
- Long Page: 10 participants
- Map-Enabled Page: 10 participants

This balanced allocation allowed a direct comparison of the three-page formats under the same study framework.

Descriptive Results

The descriptive findings suggest that the Map-Enabled Page condition produced the strongest outcomes overall, particularly in terms of perceived convenience and actual drop-off completion. The Long Page condition showed the highest score in information sufficiency, while the Short Page condition achieved acceptable usability but lower behavioral outcomes than the map-supported version.

Table 1. Mean Scores by Condition (n = 30)

Variable	Short Page (n=10)	Long Page (n=10)	Map-Enabled Page (n=10)
Drop-off Intention (1–7)	4.8	5.4	6.2
Perceived Convenience (1–7)	4.6	4.9	6.5
Information Sufficiency (1–7)	4.7	6.3	5.8
System Usability Scale (0–100)	76.0	72.5	84.2
Perceived Usefulness (1–7)	5.0	5.8	6.4



These simulated results indicate that participants who viewed the Map-Enabled Page reported the highest intention to drop off their power banks and the highest perceived convenience. This suggests that the presence of an interactive map and nearby location support may reduce user effort and make the drop-off process easier to act upon. By contrast, participants in the Long Page condition reported the greatest information sufficiency, indicating that detailed explanations may improve understanding, even if they do not produce the strongest behavioral response. The Short Page condition performed reasonably well in usability but scored lower on intention and completion-related outcomes. These patterns are consistent with the study's comparison of short, long, and map-enabled EoL passport designs described in the methodology.

Actual Drop-off Completion

Actual drop-off behavior was measured through follow-up confirmation and QR-based drop-off verification proposed in the methodology. Based on the simulated 30-participant dataset, the Map-Enabled Page again showed the strongest performance.

Table 2. Drop-off Completion by Condition

Condition	Completed Drop-off	Did Not Complete	Completion Rate
Short Page	4	6	40%
Long Page	5	5	50%
Map-Enabled Page	8	2	80%
Total	17	13	56.7%

The findings suggest that participants in the Map-Enabled Page condition were more likely to complete the drop-off action than those in the other two conditions. The Short Page yielded the lowest completion rate, while the Long Page produced a moderate result. This pattern may indicate that while concise or detailed information can increase awareness, a location-support feature may be more effective in translating intention into actual behavior.

Comparative Interpretation

Overall, the simulated data suggest three different strengths for the three page formats:

- The Short Page appears effective for simple and quick communication, but it may not provide enough support to strongly encourage actual drop-off behavior.
- The Long Page appears to improve users' understanding and perceived information sufficiency, which may be helpful for awareness-building and education.
- The Map-Enabled Page appears to offer the strongest practical support for action, leading to the highest scores in convenience, usability, intention, and actual drop-off completion.

These findings suggest that when the goal is to promote real end-of-life action, reducing practical barriers may be more important than only increasing information volume. In this simulated dataset, the ability to view nearby drop-off points and access directions likely made the task feel more manageable and immediate.



Summary of Findings

Based on the 30-participant simulated results, the Map-Enabled Page appears to be the most effective of the three lightweight digital EoL passport designs for encouraging proper power bank drop-off behavior. The Long Page provides the richest information, but its behavioral effect appears smaller than the map-supported design. The Short Page offers clarity and ease of reading, yet shows the weakest effect on actual drop-off completion. Therefore, these illustrative findings suggest that adding location-based support to a QR-linked EoL passport may be the most promising design strategy for improving responsible disposal behavior among consumers.

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