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Equity in Household Food and Packaging Waste Management: A Systematic Literature Review of Determinants, Service Design, Measurement Bias, and Inclusive Interventions

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ABSTRACT

Household food and packaging waste sit at the intersection of everyday routines and municipal service systems. Equity problems emerge when participation costs such as time, distance, storage space, and digital requirements are unevenly distributed across households. This systematic literature review synthesizes 55 Scopus-indexed journal articles published between 2020 and 2025, screened and reported using PRISMA 2020. We organize the evidence into four themes: equity determinants (gendered household labor, education-related competencies, and digital connectivity), service design mediators (coverage, proximity, pickup reliability, cleanliness, and rule clarity), measurement and bias in household waste quantification (self-report, diaries, weighing, composition audits, and smart sensing), and equity performance of packaging-oriented instruments (pay-as-you-throw pricing, deposit-return systems, extended producer responsibility, and refill or reuse models). Across contexts, equity effects are conditional on access: service reliability and convenience often explain intention-behavior gaps more than attitudes alone. Self-report methods frequently underestimate waste and overstate pro-environmental practices, while high-burden protocols risk excluding time-constrained households and biasing subgroup comparisons. We conclude with an access-first implementation roadmap and an equity-credible evaluation checklist combining affordability safeguards, low-technology participation pathways, and mixed-method measurement designs.

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1. INTRODUCTION

Household food waste and packaging waste are persistent challenges for municipal solid waste systems, circular economy strategies, and climate mitigation agendas. Although households are often treated as a single behavioral unit, the feasibility of waste prevention, sorting, and return behaviors differs across housing types, work schedules,

mobility constraints, and access to infrastructure. [1], [6], [14].

Equity is a practical condition for stable participation. Programs that shift time and effort onto households will be adopted unevenly unless services reduce friction. When convenience barriers are high, participation concentrates among households with more discretionary time, more storage space, and better proximity to services, while constrained groups face higher effective costs. [3], [4], [9].

Food waste is embedded in planning, shopping, storage, cooking, and leftover management routines. Packaging outcomes are embedded in product design, retail formats, sorting rules, and recovery infrastructure. Interventions that add steps without reducing frictions in these routines can widen gaps in participation and outcomes. [15], [23].

Equity problems are amplified by u neven exposure to packaged goods and unequal access to alternatives. Households in underserved neighborhoods may face higher shares of single-use packaging due to retail options dominated by convenience formats, while households with better access to refill systems and bulk purchasing can reduce packaging more easily. This means that packaging outcomes reflect structural constraints in consumption environments as much as household choices. [4], [11].

Evidence generation also carries equity risks. Burdensome protocols can underrepresent time-constrained households, renters, and multi-unit residents. Low-burden self-report studies can overstate desirable behaviors due to recall error and social desirability bias, producing misleading subgroup comparisons. Equity-aware synthesis therefore treats measurement burden and selection as core substantive issues, not minor technicalities. [10], [14].

This review addresses four research questions. RQ1 asks which equity-relevant determinants are most consistently associated with household food and packaging waste outcomes. RQ2 asks which service design features mediate participation and equity outcomes. RQ3 asks how measurement choices and bias affect estimates and equity inference. RQ4 asks how packaging-focused policy instruments perform across groups and which safeguards improve fairness. [13], [18].

Our contribution is to integrate household determinants, service design, measurement design, and packaging policy instruments within a single equity logic framed as participation cost. Instead of treating inequities as unexplained demographic differences, we interpret them as predictable outputs of feasibility conditions and evaluation designs, which makes the findings actionable for program design and evaluation. [15], [16].

2. LITERATURE REVIEW

2.1 Equity as participation cost and capability

Equity in household waste management can be operationalized as differences in participation cost across households. Participation cost includes time, physical effort, storage space, cognitive load from complex rules, and social risk of being judged for errors. Programs that increase any of these costs create unequal adoption even when stated support is high. [20], [22], [27].

A capability framing clarifies why access is the first lever. If households lack practical capability to comply because services are distant, unreliable, or unclear, messaging cannot close the gap. Equity depends on whether the system supplies enabling conditions such as proximity, containers, and predictable schedules, not only on whether households hold pro-environmental values. [32], [38].

Equity is dynamic. Service improvements can reduce participation cost and narrow

gaps, while new requirements without safeguards can widen gaps quickly. Equity monitoring must be continuous and tied to operational indicators such as coverage, travel time, schedule adherence, and complaint patterns that reveal how burdens distribute over space and groups. [53], [54].

2.2 *Behavioral perspectives and intention-behavior gaps*

Behavioral perspectives built around attitudes, norms, and perceived behavioral control are frequently used to explain recycling and waste prevention practices. Intentions are more predictive when services are convenient and reliable, and less predictive when households face high friction from distance, time costs, or ambiguous rules. [4], [5], [7].

For equity analysis, intention-behavior gaps are informative. When groups display similar intention but different practice, the difference often reflects unequal feasibility rather than weaker motivation. Equity-sensitive interpretations treat perceived behavioral control as a signal of constraints that should be measured directly. [3], [4]

2.3 *Practice-oriented lenses and routine mechanisms*

Practice-based lenses explain waste outcomes as the product of routines requiring materials, competencies, and shared meanings. Food waste prevention requires planning tools, storage infrastructure, and cooking flexibility. Packaging outcomes require sorting infrastructure, rule comprehension, and access to recovery pathways that fit into daily mobility patterns. [31], [34].

This lens explains why small service features can have large effects. Container placement, operating hours, the number of sorting categories, and cleanliness of shared waste rooms can change feasibility more than values or awareness in the short term. [8], [11].

2.4 *Service design as mediator of equity*

Service design features such as coverage, proximity, pickup frequency, cleanliness, and rule stability mediate the link between household characteristics and outcomes. Mixed findings in determinants studies can often be reconciled once service context is considered because feasibility conditions determine whether skills and norms translate into action. [14], [16], [17].

Multi-unit housing introduces distinct governance and space constraints. Shared waste rooms, contested responsibility, and limited storage create structural barriers not captured by typical household survey variables. Equity-focused programs require building-level solutions rather than relying only on individual behavior change strategies. [9], [10].

2.5 *Measurement choices as equity choices*

Measurement approaches range from self-report surveys and diaries to weighing, composition audits, and sensor-based systems. Each method trades off scale, validity, and burden. These tradeoffs influence who participates and therefore what inequities are visible in the data. [19], [42].

Self-report methods tend to underestimate waste and overstate compliance, while high-burden direct methods can exclude constrained households and distort subgroup comparisons. Smart systems can reduce manual burden but introduce digital exclusion and privacy governance issues that can themselves become equity barriers. [3], [25].

2.6 Packaging policy instruments and distributional effects

Packaging-focused instruments operate through both household behavior and upstream responsibilities. Pay-as-you-throw pricing and deposit-return systems change household costs and incentives. Extended producer responsibility shifts costs and aims to drive redesign, while refill and reuse models aim to reduce single-use demand. [14], [21], [24].

Equity issues arise through affordability, convenience, and infrastructure access. If return locations are sparse, deposits behave like friction costs. If pricing schemes are implemented without allowances, burdens can be regressive. Equity-sensitive design requires safeguards and investment in accessible infrastructure. [25], [55].

3. METHODS

This study follows a systematic literature review design and reports the process using PRISMA 2020. The review focuses on empirical household-level studies examining socio-demographic determinants, service design conditions, measurement protocols, and intervention effects related to food waste, packaging waste, and household waste management behaviors. [44], [47].

The search was conducted in Scopus using a Boolean string combining socio-demographic terms with household waste management terms in titles, abstracts, and keywords. Filters were applied for 2020 to 2025, document type journal article, language English, and subject areas environmental science and social science. Screening counts are summarized in Table 1 and visualized in Figure 1. [13], [52].

Eligibility required household-level outcomes or behaviors related to food waste, packaging, recycling, or sorting, and inclusion of at least one equity-relevant variable or design feature such as socio-demographics, housing constraints, access conditions, or affordability. Review papers, editorials, books, and conference proceedings were excluded. [14], [15].

Data extraction captured study context, sampling approach, outcome definitions, measurement protocols, and reported determinants or intervention components. Equity variables were coded as gender roles or sex, education and literacy proxies, income and affordability measures, digital connectivity, housing type, and mobility constraints where reported. Service mediators were coded as coverage, distance or travel time, pickup frequency and reliability, cleanliness, rule clarity, and communication channels. [16], [20], [22].

Synthesis used narrative and thematic approaches. Studies were grouped into four themes aligned with the research questions and compared for mechanisms, moderators, and implementation implications rather than pooled into a single effect size. Measurement heterogeneity and context specificity make narrative synthesis more appropriate for equity interpretation. [18], [19].

Measurement burden and participation patterns were treated as risk-of-bias considerations. For self-report studies, recall windows, question framing, and desirability mitigation were noted. For direct methods, recruitment, dropout, and representativeness checks were noted when available. These features determine whether

subgroup comparisons are credible rather than artifacts of selection. [42], [44].

Table 1. PRISMA 2020 screening summary.

Stage	Count	Notes
Records identified (Scopus)	142	Keyword search
Records after year filter (2020-2025)	81	Publication year filter
Records after document type filter (articles)	72	Journal articles only
Records after subject area filter	55	Environmental science and social science
Studies included in synthesis	55	Final included studies

Figure 1. PRISMA 2020 Flow Diagram for Identification, Screening, Eligibility, and Inclusion

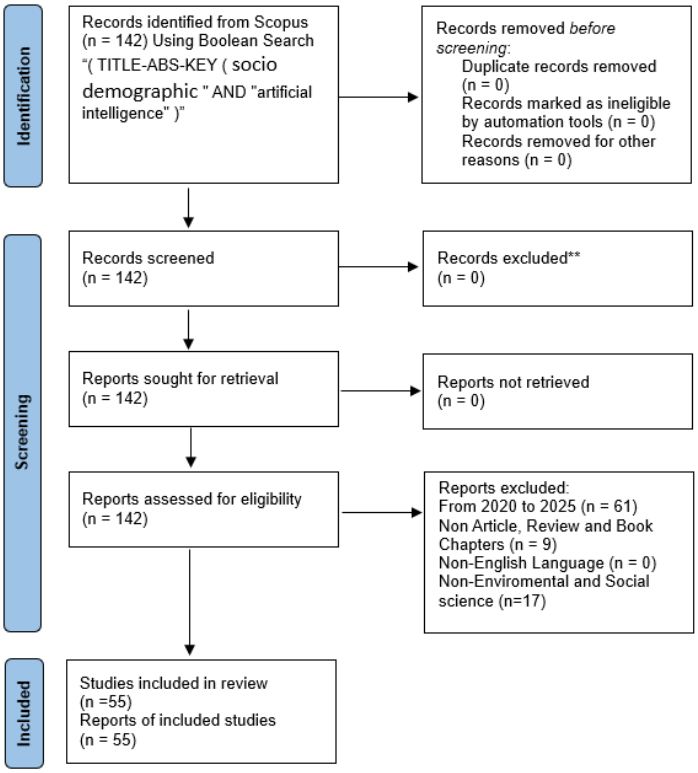

Table 2. Review Scope, Eligibility, And Coding Dimensions.

Component	Operationalization	Equity relevance
Database	Scopus	Consistency of indexing and exportability
Time window	2020-2025	Recent policy and measurement shifts
Document type	Journal articles	Peer-reviewed evidence base
Domains	Environmental science; Social science	Behavior and system design jointly
Outcomes	Food waste; packaging waste; recycling/sorting; related behaviors	Behavioral and material outcomes
Equity variables	Gender roles, education/literacy, income/affordability, digital connectivity, housing, mobility	Proxies for capability and burden
Service mediators	Coverage, distance, reliability, cleanliness, rule clarity, communication	Defines participation cost
Measurement protocols	Self-report, diaries, weighing, audits, sensing	Validity and representativeness tradeoffs

Table 3. Evidence Map of Included Studies (n = 55) Based on RIS Export Metadata.

ID	Study (first author, year)	Context (as reported)	Primary focus	Design signal
1	Kaptan (2025)	United Kingdom	Food waste	Waste audit
2	Meidiana (2025)	Indonesia	Illegal dumping/litter	Modeling
3	Adeleke (2025)	South Africa	Municipal solid waste	Modeling
4	Armenta-Vergara (2025)	Colombia	Packaging/plastics; Recycling/sorting	Survey
5	Trujillo (2025)	Chile	Recycling/sorting	Choice experiment
6	Ananda (2025)	Australia	Food waste	Modeling
7	Mintas (2025)	Romania	Recycling/sorting	Waste audit
8	Saxena (2025)	Canada	Recycling/sorting	Survey
9	Fontaine (2025)	Canada	Municipal solid waste	Modeling
10	Lapore (2025)	Philippines	Municipal solid waste	Survey
11	Djebar (2025)	Algeria	Packaging/plastics; Recycling/sorting	Survey
12	Okin (2024)	Japan	Illegal dumping/litter	Survey
13	Akbar (2024)	Pakistan	Municipal solid waste	Survey
14	Hidalgo-Crespo (2024)	France	Food waste; Packaging/plastics	Survey
15	Bilska (2024)	Poland	Food waste	Survey
16	Singh (2024)	India	Recycling/sorting	Survey
17	Khorief (2024)	Algeria	Recycling/sorting	Survey
18	Al Refaee (2024)	United States	Municipal solid waste	Survey
19	Taye (2024)	Ethiopia	Municipal solid waste	Survey
20	Srivastava (2023)	India	Municipal solid waste	Modeling
21	Lavallee (2023)	Canada	Packaging/plastics	Survey
22	Patra (2023)	India	Municipal solid waste	Modeling
23	Kusumawardani (2023)	Indonesia	Food waste	Modeling
24	Puntarić (2022)	Croatia	Packaging/plastics; Recycling/sorting	Modeling
25	Abrokwah (2022)	Ghana	Packaging/plastics; Recycling/sorting	Mixed/Other
26	Premoli Vilà (2022)	Italy	Recycling/sorting	Modeling
27	Rathnamala (2022)	India	Municipal solid waste	Survey
28	Schoeman (2022)	South Africa	Recycling/sorting	Survey
29	Lozano Lazo (2022)	USA	Recycling/sorting; Illegal dumping/litter	Survey
30	Kandpal (2022)	India	Municipal solid waste	Survey
31	Souissi (2022)	Tunisia	Food waste	Modeling
32	Dunkel (2022)	Germany	Municipal solid waste	Modeling
33	Anjum (2022)	India	Recycling/sorting	Survey
34	Piras (2022)	Italy	Food waste; Recycling/sorting	Survey
35	Roos (2022)	South Africa	Municipal solid waste	Survey
36	Music (2021)	Canada	Food waste	Survey
37	Jereme (2021)	Malaysia	Food waste	Survey
38	Rosecký (2021)	Czech Republic	Recycling/sorting	Modeling
39	Ananda (2021)	Australia	Food waste	Modeling
40	Kumar (2021)	India	Recycling/sorting	Survey
41	Popli (2021)	South Korea	Municipal solid waste	Modeling
42	Esmalian (2021)	United States	Municipal solid waste	Survey
43	Portugal (2020)	United States	Food waste	Survey
44	Yang (2020)	China	Municipal solid waste	Qualitative

45	Wang (2020)	China	Recycling/sorting	Survey
46	Mu'azu (2020)	Saudi Arabia	Recycling/sorting	Survey
47	He (2020)	Australia	Municipal solid waste	Modeling
48	Herzberg (2020)	Germany	Food waste	Survey
49	Rousta (2020)	Sweden	Recycling/sorting	Mixed/Other
50	Heidari (2020)	Iran	Food waste	Survey
51	Ilakovac (2020)	Croatia	Food waste	Modeling
52	Angeline J (2020)	India	Municipal solid waste	Survey
53	Thu Nguyen (2020)	Vietnam	Recycling/sorting	Modeling
54	Staudacher (2020)	Switzerland	Municipal solid waste	Survey
55	Chikowore (2020)	United States	Packaging/plastics; Recycling/sorting	Survey

4. RESULTS AND DISCUSSION

The PRISMA flow in Figure 1 shows that 55 studies met eligibility criteria after filtering and screening. The evidence base is methodologically diverse, spanning surveys, choice experiments, waste audits, and predictive modeling. Outcomes are heterogeneous. Food waste is reported as mass, avoidable share, frequency, or proxy practices, while packaging outcomes are reported as participation, return rates, contamination, or willingness to adopt refill and reuse behaviors [47], [52].

Instead of treating heterogeneity as noise, we interpret it as part of the phenomenon. Different outcomes and methods capture different layers of the system, from daily routines to infrastructure constraints. The synthesis emphasizes mechanisms and moderators that explain when determinants appear, when interventions succeed, and when equity gaps widen or narrow [27], [32].

Across themes, three moderators recur: convenience and reliability of services, housing conditions that constrain storage and shared governance, and measurement burden coupled with reporting bias. These moderators connect determinants, service design, measurement design, and policy instruments into a unified equity narrative framed as participation cost [38], [53].

4.1 Equity determinants of household food and packaging waste outcomes

This subsection synthesizes evidence on socio-demographic and capability-related determinants. Determinants include gendered allocation of household labor, education and literacy proxies, income-related affordability, and digital connectivity. These determinants matter because they shape the ability to manage routines and comply with system rules, not merely because they correlate with attitudes [3], [4], [54].

Gender differences are often reported using sex categories, but the actionable mechanism is task allocation. Planning meals, managing leftovers, cleaning packaging, and ensuring correct sorting can fall unevenly on specific members. When interventions add steps or require extra trips to return points, they can increase unpaid labor and widen inequity even if aggregate waste decreases [9], [10].

Education proxies both awareness and competence. Higher education can support planning and portioning that reduce avoidable food waste, yet it can also be associated with higher consumption variety and packaged product use. The association depends on whether the outcome is avoidable mass, total waste, or proxy behaviors such as planning frequency and label comprehension [36], [37], [39].

Income and affordability shape both consumption patterns and the capacity to participate. Household budgets influence the frequency of shopping trips, the ability to buy in bulk, and the trade-off between time and money when choosing convenient packaged foods. On the participation side, affordability determines whether households can absorb fees, purchase required containers, or spend money on transport to drop-off and return

points. When cost-shifting is embedded in program design, the system effectively taxes constrained households for structural barriers they did not choose [4], [11].

Digital connectivity reduces frictions by providing schedule information, sorting guidance, and incentive feedback. However, app-only participation pathways and QR-code requirements can exclude households with limited data access, older residents, or households sharing devices. Equity-sensitive programs provide non-digital channels such as printed guides, hotlines, and in-person support so that participation is not conditioned on device ownership or digital literacy [14], [15].

Age and life-course dynamics matter because routines and constraints change. Older adults may have more time for careful sorting but face mobility barriers for distant return systems and may be less comfortable with app-based participation. Families with young children face higher time scarcity and high volumes of packaging from products marketed for convenience and safety. Students and renters face housing instability that undermines habit formation and limits investment in storage and containers. These dynamics suggest that one-size programs can look effective on average while failing specific groups [16], [20].

Housing type and household composition are critical moderators. Dense and multi-unit housing reduces storage space for multiple bins and introduces building-level governance challenges. Household size and the presence of children shape meal frequency and leftover dynamics. Mobility constraints shape feasibility of distance-based systems such as deposit returns. These constraints help explain why demographic predictors can look inconsistent when service context is not measured [43], [48].

Equity effects are rarely single-variable stories. Constraints stack. A household can be simultaneously time-poor, mobility-constrained, and living in a multi-unit building with low-quality services. In such cases, the marginal benefit of another information campaign is low, while the marginal benefit of an access upgrade is high. Research designs that look only at main effects can miss this stacking and can misinterpret constraints as weak motivation. Future studies should therefore test interactions among access, housing, and socio-demographics, and report subgroup results in ways that can guide targeted service improvements [22], [27].

A practical implication is that demographic variables should not be treated as final explanations. They are often proxies for constraints such as time, space, mobility, and access. Equity-sensitive analysis should measure constraints directly where possible and interpret demographic gradients as conditional on service design and housing context [32], [38].

Table 4. Equity Determinants, Mechanisms, and Design Implications Framed as Participation Cost.

Determinant	Mechanism	Typical barrier	Equity-sensitive response
Gendered routine labor	Unequal allocation of planning and sorting tasks	Added steps concentrate unpaid time burden	Reduce steps; integrate into routines; convenient access
Education and literacy	Rule comprehension and planning competence	Complex labels and unstable rules	Simplify and standardize; multi-format guidance
Income and affordability	Ability to absorb fees and travel costs	Regressive fees and transport costs	Allowances, exemptions, and dense access points
Digital connectivity	Access to information and feedback	App-only systems and data costs	Offline options; assisted participation
Housing type	Space and shared governance	Insufficient storage and contested shared rooms	Building-level services; container provision
Mobility and age	Physical access and travel feasibility	Distance, queues, and carrying burden	Proximity; extended hours; pickup alternatives
Time constraints	Opportunity cost of compliance	Multiple trips, long queues	Reduce time burden; align with routines

4.2 Service Design as Mediator of Equity

In this subsection shows that service design is a primary mediator of equity outcomes. Coverage, proximity, pickup frequency, cleanliness, and rule clarity determine the time and effort required for participation. When services are weak or ambiguous, feasibility dominates and household characteristics become less predictive [24]-[26].

Coverage and distance define the geometry of convenience. When drop-off sites or return points are sparse, participation depends on transport access and discretionary time. Because mobility resources are unevenly distributed, distance-based systems are structurally unequal unless offset by dense networks, extended operating hours, and the option of curbside pickup or mobile collection [53], [54].

Service inequity is often spatial. Rural areas may be offered fewer streams and lower pickup frequency due to higher logistics costs, while dense urban neighborhoods may have higher service density but more multi-unit governance problems. Within cities, underserved neighborhoods can face both poorer service and higher exposure to litter and illegal dumping. Equity therefore requires mapping not only who participates, but who is offered a feasible opportunity to participate [3], [4].

Pickup reliability shapes burden and trust. Irregular pickup increases storage requirements, odor and pest risk, and frustration. These burdens are more severe for small dwellings and dense housing where storage is limited. Reliability also shapes perceived fairness because households need to see that effort is matched by system performance; otherwise, households interpret participation as wasted time and may disengage [28], [29].

Cleanliness and maintenance influence dignity and safety. Poorly maintained sites can generate stigma and reduce participation, particularly for groups facing greater safety risk or harassment. Maintenance and clear responsibility allocation reduce barriers and can improve both equity and aggregate participation. Maintenance is also an information signal: clean systems communicate that the municipality takes the program seriously, which supports long-term compliance [9], [10].

Rule clarity and stability reduce cognitive load. Fine-grained categories and strict cleaning requirements can shift labor onto households and create unequal compliance. Frequent changes in labeling or collection rules disproportionately harm households with limited time to learn updates and households with language barriers. Equity-sensitive rule design prioritizes simplicity and stability, with visual cues that are usable at a glance [33], [34].

Multi-unit housing requires building-level solutions. Shared waste rooms can become contested spaces where no single household can ensure cleanliness or rule compliance. Programs that ignore building-level governance risk blaming households for failures that are actually infrastructure and management problems. Equity-sensitive approaches include building-level container provision, service contracts, and explicit cleaning responsibilities shared between landlords, building managers, and service providers [14], [15].

Enforcement and penalties are a service design decision because they shape participation cost through risk. If fines are applied before access barriers are removed, penalties function as inequitable taxation. Proportional enforcement sequences warnings and education, targets chronic contamination problems with supportive interventions, and couples penalties with evidence that services are reliable and accessible. This reduces the likelihood that enforcement intensifies mistrust and disengagement in underserved neighborhoods [16], [20].

Table 5. Service Design Levers, Equity Risks, and Operational Responses.

Service lever	Equity risk when weak	Observable indicator	Equity-sensitive response
Coverage	Structural exclusion	Households served (%)	Expand coverage; prioritize underserved areas
Proximity	Time and mobility burden	Travel plus queue time	Increase access points; extend hours
Reliability	Storage and frustration burden	Pickup adherence	Stabilize schedules; backup options
Cleanliness	Stigma and safety risk	Site condition score	Routine maintenance; clear responsibility
Rule clarity	Cognitive load and fines	Comprehension checks; error rate	Simplify and standardize; guidance
Containers	Cost shifted to households	Bins available per building	Provide bins; building-level solutions
Communication	Information inequality	Multi-channel reach	Printed guides; hotline; in-person support
Governance	Mistrust and resistance	Complaints; trust surveys	Transparency; feedback loops; proportional enforcement

4.3 Measurement and Bias in Household Waste Quantification

This subsection treats measurement as a determinant of what the literature appears to show. Methods shape both validity and representativeness. A method can produce precise estimates yet still mislead if it systematically excludes constrained households or if bias differs across groups [13], [18].

Self-report surveys scale well but are vulnerable to recall error and social desirability bias. Recall windows influence accuracy, and respondents can differ in what they classify as avoidable waste. Underreporting is rarely random. If particular groups feel judged or have stronger environmental identities, they may underreport more, distorting equity inference [50], [51].

Diary methods reduce recall error but introduce fatigue. Completion rates can differ by time availability, literacy, and household disruption. If completion is lower among constrained households, estimates become overly optimistic and subgroup comparisons become biased toward organized households with more capacity. Shorter diary windows and simplified logging can reduce differential attrition but may sacrifice detail [1], [6].

Direct weighing and composition audits improve validity and allow fraction-level analysis, but they impose burden through storage, scheduling, and intrusiveness. These requirements can reduce participation among renters, households with irregular work schedules, and households with limited space. Studies using direct methods should report recruitment, dropout, and representativeness checks as central results and should design protocols that minimize household effort [14], [15].

Smart sensing and data-driven approaches reduce manual burden and provide high-frequency measurement, but they introduce digital inclusion and privacy governance issues. If smart systems are deployed first in affluent neighborhoods, data will overrepresent those contexts and misstate equity performance. Equitable deployment requires balanced siting, transparent data policies, and opt-out or low-technology alternatives that preserve participation without surveillance pressure [30]-[32].

Measurement error interacts with equity analysis through two pathways. First, random error inflates variance and makes true subgroup differences harder to detect. Second, systematic error shifts means and can create spurious subgroup differences. For

example, if one group systematically underreports avoidable waste more than another, an analysis may falsely attribute the gap to behavior rather than reporting style. This is why validation subsamples and calibration models are not optional extras for equity work [19], [42].

A pragmatic design is two-stage measurement. Stage 1 uses low-burden surveys to cover large samples, mapping access conditions, perceived burdens, and reported behaviors. Stage 2 selects stratified subsamples for objective measurement using weighing or audits, with oversampling of groups likely to be underrepresented. Calibration estimates can then adjust reported quantities and quantify uncertainty. This approach preserves scale while improving validity and avoids excluding constrained households from the evidence base [44], [47].

Ethical and governance issues are part of measurement quality. Sensor-based systems and image recognition can create chilling effects if households fear surveillance or penalties. Equity-sensitive governance requires purpose limitation, transparent data retention rules, and community communication that emphasizes service improvement rather than punishment. Without this, measurement itself can become a barrier that worsens inequity [33], [38].

Table 6. Measurement Methods, Equity Risks, and Mitigation Options.

Method	Strength	Equity risk	Mitigation
Self-report survey	Scalable, low cost	Recall and desirability bias	Neutral wording; short recall; validation
Diary	Lower recall error	Fatigue; differential completion	Short duration; simple tools; monitor missingness
Weighing	High validity	Burden; space constraints	Provide containers; flexible pickup; report dropout
Composition audit	Detailed fractions	Intrusiveness; privacy concerns	Consent; anonymization; minimal effort
Smart bin sensors	Passive time series	Unequal deployment; surveillance concerns	Equitable siting; transparent governance; opt-out
Image recognition	Sorting feedback	Algorithmic error and bias	Bias testing; human review; error reporting
App reporting	Real-time tracking	Digital exclusion	Offline pathways; assistance; no-cost participation
Mixed-method design	Balances scale and validity	Operational complexity	Stratified design; preregistered protocols

4.4 Packaging-Focused Instruments and Equity Performance

In this part, focuses on packaging instruments designed to reduce single-use materials and increase recovery. Equity performance depends on affordability, convenience, and access to infrastructure. Instruments can shift burdens across households if safeguards are not built in from the start [14], [21], [24].

Pay-as-you-throw pricing can reduce residual waste by increasing disposal cost, but equity risks arise because some waste generation is linked to household needs and housing context. Without allowances and accessible recycling and organics pathways, pricing can become regressive and can incentivize avoidance behaviors such as illegal dumping or shifting waste into public bins, which then externalizes costs to neighborhoods [25], [55].

Deposit-return systems can achieve high return rates when return options are convenient and redemption is simple. Equity issues arise when return points are distant, operating hours are limited, or systems rely on digital interfaces. In such cases deposits act as friction costs and can transfer money from households with less time and mobility to those with more. Dense networks, extended

hours, and cash redemption reduce this regressivity [4], [11].

Extended producer responsibility shifts recovery costs upstream and incentivizes redesign, but equity concerns arise when costs pass through to consumers and when labeling assumes high literacy or smartphone scanning. Equity-sensitive implementation includes standardized labels, producer-funded infrastructure targeted to underserved areas, and monitoring of consumer price impacts for essential goods so that improved packaging does not unintentionally increase living costs for vulnerable households [14], [21].

Refill and reuse models can reduce packaging demand, yet adoption is constrained by convenience, hygiene trust, and time. If participation requires extra trips, complex container rules, or app-only loyalty systems, uptake concentrates among households with more discretionary time. Equity-sensitive refill design integrates stations into routine retail pathways, provides standardized containers, and offers non-digital participation so that savings do not require a smartphone [24], [25].

E-commerce and delivery formats are a growing packaging driver and have distinct equity patterns. Delivery can reduce time burdens for some households, yet it can increase packaging volumes and shift waste handling to households. Households with limited storage space face higher burdens from bulky cardboard and protective materials. Equity-sensitive strategies include producer-funded take-back options, collection partnerships with last-mile providers, and building-level collection solutions for multi-unit housing [4], [55].

Across instruments, accessibility metrics should be treated as core performance criteria. Travel time, queue time, operating hours, and availability of cash or manual pathways often determine equity outcomes more than the nominal incentive level. For evaluation, it is not enough to report overall return rates; programs should report how return rates and burdens vary by area and by constraints such as mobility and housing type [22], [27].

Table 7. Equity Safeguard Matrix for Common Packaging Instruments.

Instrument	Core equity risk	Access safeguard	Affordability safeguard	Low-technology option
PAYT pricing	Regressive burden; dumping risk	Free recycling and organics; convenient drop-off	Allowance; exemptions; caps	Paper billing; assisted sign-up
Deposit-return	Exclusion by distance and queues	Dense network; extended hours	Transparent payouts	Manual returns; cash payout
EPR	Price pass-through; label confusion	Fund infrastructure; standardized labels	Monitor prices; protect essentials	Labels readable without scanning
Refill/reuse	Time burden; hygiene trust	Integrate into retail routes	Refundable deposits; universal discounts	Non-app loyalty; staff assistance
Sorting mandates	Space and complexity burden	Provide bins; simplify rules	Delay fines until services reliable	Printed guides; hotline support
Smart systems	Privacy and digital exclusion	Equitable siting; opt-out	No household cost shift	Non-digital participation

4.5 Cross-Theme Synthesis: Access-First Sequencing and Equity-Credible Evaluation

Access conditions are the strongest leverage point for equity. When services are unreliable, interventions become unevenly

effective and compliance burdens concentrate among households with the least time and space. Access-first service improvements can outperform information-only campaigns in both equity and overall effectiveness [32], [38].

Equity-sensitive implementation is sequencing. Programs that begin with messaging and escalate to penalties while leaving access barriers unchanged tend to widen inequity. A defensible pathway begins with diagnosing service gaps and reducing participation cost before intensifying incentives or enforcement [53], [54].

Stage 1 maps feasibility using coverage, travel time, operating hours, pickup adherence, cleanliness, and rule complexity, with attention to multi-unit buildings and low-mobility groups. Stage 2 deploys enabling infrastructure such as containers, stable schedules, clean sites, and simplified rules. Stage 3 layers stronger instruments such as pricing or deposits with explicit safeguards. Stage 4 institutionalizes learning through continuous monitoring and transparent feedback loops [13], [52].

Evaluation design must match equity objectives. If a protocol excludes constrained households, it will overstate success and understate barriers. Equity-credible evaluation requires reporting participation and completion rates, checking selection bias, and triangulating self-report with objective measures in stratified validation subsamples [18], [19].

Packaging policy requires safeguards as core parameters. Pricing and deposit schemes can become regressive if affordability and accessibility are not addressed. Producer responsibility schemes can create distributional effects through price pass-through and unequal infrastructure investment. Equity-sensitive governance combines access metrics with affordability monitoring and accountable reporting [11], [14].

4.6 Equity Indicators and Operational Definitions for Monitoring

Equity monitoring should include both participation and burden outcomes. Participation includes enrollment, sustained participation, correct sorting, and contamination rates. Burden includes travel and queue time, time spent preparing materials, storage requirements, and availability of low-technology alternatives. Tracking only waste quantities can hide inequity because reductions can be driven by dropouts rather than broad uptake [3], [4].

Operational definitions should be specified in advance. Accessibility for deposit systems is better measured as travel time plus queue time during operating hours than as straight-line distance. Affordability for pricing can be measured as fee burden relative to income and exemption coverage. Feasibility of sorting mandates can be assessed via container access, comprehension checks, and observed contamination [21], [24].

Indicators should be disaggregated by neighborhood and vulnerability proxies such as dense housing, low mobility, or limited connectivity. Disaggregation detects whether improvements concentrate in advantaged areas and whether program changes create new barriers. Equity indicators support adaptive management by identifying where service upgrades should be prioritized [9], [10].

A monitoring design can combine routine administrative indicators, such as pickup adherence and complaints, with periodic household surveys and targeted audits in stratified areas. This enables system accountability while preserving subgroup learning without relying solely on biased self-report measurements [42], [44].

Table 8. Example Equity Indicators for Household Waste and Packaging Interventions.

Domain	Indicator	Operational definition	Equity purpose
Access	Coverage rate	Households with curbside service or nearby drop-off	Detect structural exclusion

Access	Travel plus queue time	Minutes to access point including queues	Measure time burden distribution
Reliability	Pickup adherence	Pickups completed on schedule	Track burden from missed service
Rules	Comprehension score	Short checks about rules	Identify cognitive load and confusion
Burden	Container availability	Bins provided per household/building	Detect cost shifting
Affordability	Fee burden	PAYT fee as share of income; exemption coverage	Detect regressivity
Participation	Sustained participation	Active participation after 3-6 months	Separate adoption from novelty
Quality	Contamination rate	Non-target share in stream	Monitor penalization risk
Trust	Perceived fairness	Survey score plus complaints	Link governance to persistence

4.7 Implementation roadmap and design recommendations

Equity-sensitive programs should prioritize convenience before persuasion. Investing in proximity, predictable schedules, safe and clean sites, and simplified rules reduces participation cost for everyone but disproportionately benefits households with constrained time and mobility. This simultaneously narrows gaps and raises aggregate performance [14], [15].

Pricing and deposit instruments should be implemented only when baseline access is secured. For pay-as-you-throw this includes free or low-cost access to recycling and organics services and allowances protecting low-income households and large families from regressive burdens. For deposit systems this includes dense return infrastructure and cash redemption pathways that do not require smartphones or bank accounts [25], [55].

Communication should be designed for heterogeneous capabilities. Printed materials, visual rule guides, and hotlines remain important even in highly digital contexts. In multi-unit buildings, building managers and shared governance arrangements are part of the intervention. Programs should assign responsibility for containers and cleanliness explicitly to avoid blame shifting onto residents [38], [40].

Evaluation should be planned together with implementation. Equity-sensitive evaluation includes burden metrics, subgroup completion rates, and validation subsamples. Reporting should include the operational context required to interpret whether gaps reflect feasibility constraints or measurement artifacts. This reduces the risk of policy being built on biased evidence [47], [52].

Finally, equity and resilience are linked. During shocks such as pandemics, economic downturns, or supply-chain changes, households can experience rapid shifts in packaged food reliance, shopping frequency, and waste composition. Systems that rely on fragile participation pathways can see equity gaps widen quickly under stress. An equity-sensitive research agenda should therefore examine how interventions perform under changing conditions, and whether safeguards such as allowances, flexible redemption, and reliable service act as stabilizers that protect both participation and outcomes [42], [44], [47].

Multi-unit housing deserves specific policy attention because it concentrates constraints: limited space, shared governance conflicts, and higher sensitivity to missed pickups and cleanliness. Interventions such as building-level container provision, redesigned waste rooms, and negotiated service agreements with building managers can change feasibility more than any messaging campaign. Equity-focused evaluation should report building-type strata explicitly and treat building-level variables as part of the causal pathway rather than nuisance controls [4], [5], [7].

Policy implications extend beyond municipal services to producer and retailer responsibilities. In many contexts, households are asked to solve packaging outcomes that are partially created upstream through product design and retail formats. Equity-sensitive governance therefore needs coordination between municipalities and extended producer responsibility organizations, including targeted infrastructure funding for underserved neighborhoods and design standards that reduce sorting complexity. If producers fund recovery, the distribution of funding should reflect exposure and burden, not only volumes captured in affluent areas where participation is already high [4], [11], [14].

Beyond measurement, equity should be embedded in decision rules. For example, a municipality can adopt a rule that no pricing or penalty escalation occurs until pickup reliability exceeds a threshold and until access point density achieves a travel-time target for underserved areas. These thresholds turn equity from an aspiration into an operational trigger. They also protect the program from backlash by ensuring households are not punished for system failures. This kind of sequencing can be audited and reported in a simple timeline that shows when each safeguard came online relative to enforcement and outcome changes [10], [14], [15].

The fourth element is governance and ethics. Smart bins, image recognition, and app-based reporting can make monitoring easier but can also change behavior through fear of surveillance, especially when enforcement is linked. Equity-credible evaluation therefore requires transparent data governance: purpose limitation, clear retention rules, minimal personally identifiable data, and explicit separation between monitoring for service improvement versus monitoring for punishment. Programs should report these safeguards as part of the method because trust and privacy are not background conditions; they are participation conditions, and participation is the outcome we are trying to measure fairly. [3], [25], [30]

The third element is triangulation and calibration. A common design is to use a large survey to characterize access, perceptions, and reported behaviors, then select a stratified validation subsample for objective measurement using weighing or composition audits. Calibration models can quantify systematic underreporting and adjust estimates while preserving uncertainty. For packaging instruments, validation should include return transaction data where available, but analysts must still examine who is missing from those administrative datasets, because non-participation can look like missing data rather than a policy failure. Triangulation reduces the risk that equity conclusions are artifacts of method choice [1], [6], [14].

The second checklist element is burden and participation accounting. Evaluations should report recruitment rates, completion rates, and dropout by subgroup and by constraint proxies such as dense housing, shift work, and limited mobility. Burden indicators include minutes per week spent sorting and transporting materials, space required for storage, and frequency of rule-related errors. If a study cannot show that constrained households are represented and retained, subgroup comparisons can be misleading. This applies both to high-burden measurement protocols and to low-burden self-report surveys because the latter can still be biased by differential desirability and comprehension [13], [18], [19].

Equity-credible evaluation is not a separate add-on to program evaluation; it is the minimum standard when interventions impose different burdens across households. A practical checklist starts with baseline access mapping: coverage, travel plus queue time, container provision, operating hours, and pickup reliability by neighborhood and housing type. If baseline access is unequal, then average outcomes cannot be interpreted as household performance because they are partly engineering outcomes. The checklist therefore treats access diagnostics as the first step and the first table in reporting, before any behavior modeling or policy claims [3], [4], [9].

4.8 Equity-Credible Evaluation Checklist

Fifth, more evidence from diverse socio-economic and governance contexts is needed, especially where informal housing, intermittent services, and mixed public-private waste systems are common. Equity mechanisms can differ when households rely on informal recycling networks, when municipal coverage is incomplete, or when waste fees are collected through nonstandard channels. Research should document how interventions interact with informal actors and how equity safeguards can be designed without undermining livelihoods. This is also where policy learning is richest because constraints are visible and improvisation is frequent [27], [32], [38].

Fourth, measurement science needs explicit equity benchmarks. Studies should report measurement burden, differential completion, and calibration results as primary outcomes. When objective measurement is infeasible at scale, researchers can develop standardized correction factors using validation subsamples, and can quantify uncertainty introduced by reporting bias. Emerging sensing technologies should be evaluated not only for accuracy but for distributional impacts: where they are deployed, who opts out, and whether algorithmic errors vary by context or material type [31]-[33].

Third, intervention studies should test specific equity safeguards rather than only overall programs. For pricing, this means experimentally varying allowance structures, exemption criteria, and communication formats. For deposit systems, this means testing return-point density, cash versus digital redemption, and operating-hour extensions. For refill systems, this means testing station placement along routine retail routes and non-digital participation options. Design-of-experiments approaches can identify which components reduce burden for constrained households and which components inadvertently exclude them [21], [24], [25].

Second, multi-level modeling should become standard. Household outcomes are nested within buildings, neighborhoods, and service districts. Without multi-level structures, analyses can misattribute system-level differences to household characteristics. Studies should measure service context directly: pickup frequency and adherence, access point density, operating hours, and rule complexity. Building-level variables such as waste-room design, container provision, and management practices are often stronger predictors than individual demographics in dense housing [16], [20], [22].

First, the field needs more longitudinal designs that distinguish short-term adoption from durable participation. Many interventions show early enthusiasm, but equity gaps can emerge through dropout when burdens accumulate. Tracking households across months and seasons is essential because food waste varies with routines, celebrations, and price dynamics, and because packaging flows vary with product availability and delivery patterns. Longitudinal designs also enable analysis of whether service upgrades reduce inequity over time or whether benefits concentrate in early-adopting groups [13], [18], [52].

4.9 Future research directions for equity and household waste systems

Eighth, the field would benefit from shared reporting standards. At minimum, studies should report service context variables, measurement burden indicators, and representativeness checks in a common format to support synthesis. Standardized definitions for avoidable food waste, packaging fractions, and contamination would improve comparability. Where possible, researchers should publish codebooks and anonymized derived datasets or summary statistics that allow reanalysis of equity claims without exposing sensitive household information. This would move the literature from narrative disagreement toward cumulative learning [19], [42], [44].

Seventh, participatory and co-design approaches can prevent blind spots. Households experiencing the highest burdens are often those least represented in surveys and trials. Co-design workshops with residents from dense housing, older adults, shift workers, and low-connectivity groups can identify failure points early, such as operating hours mismatched to work schedules or rule communications that require internet access. Importantly, co-design should be linked to operational authority so that identified barriers translate into concrete service changes rather than only education materials [3], [53], [54].

Sixth, equity analysis should be paired with economic analysis that explicitly tracks who pays and who benefits. Many waste and packaging instruments change the distribution of costs through fees, deposits, time burdens, and product price pass-through. Traditional cost-benefit analyses often treat time costs implicitly or average them across populations. Equity-credible appraisal should quantify time and transport burdens, estimate distribution across income and mobility groups, and include scenario analysis on safeguard design. This also supports transparent political decision-making because it makes trade-offs visible rather than hidden inside aggregate efficiency claims [4], [11], [55].

Finally, communication design deserves deeper study as an equity lever. Sorting rules are often delivered through dense text, fine print, or web pages that presume stable internet access and high literacy. Research should test whether visual, multilingual, and at-a-glance rule systems improve correctness and reduce anxiety about making mistakes, especially in diverse neighborhoods and in multi-unit housing where shared rooms amplify the social consequences of errors. Communication that lowers cognitive load can function as a low-cost equity intervention when combined with stable and reliable services [8], [11], [14].

An additional research and practice need is better integration between equity metrics and real-time operations. Many municipalities already collect administrative data on missed pickups, complaint calls, contamination tags, and route performance. These streams can be linked to neighborhood vulnerability indicators to create early warnings of emerging inequity. For example, a sudden rise in contamination tags in an area may signal that rules changed without adequate communication or that containers are insufficient for the housing mix. Using administrative indicators for adaptive management can reduce reliance on infrequent surveys and can make equity improvements faster and more targeted [4], [9], [10].

From a methodological standpoint, reporting should distinguish equity in outcomes from equity in opportunities. An outcome gap can shrink because disadvantaged households leave the program, which is an equity failure masked as improvement. Opportunity metrics such as access time, availability of containers, and frequency of service failures provide a clearer picture of whether the system is becoming fairer. Future work should therefore report both outcome trajectories and participation trajectories, and should interpret waste reductions alongside enrollment and retention patterns. This distinction matters because dashboards can improve while the system becomes less inclusive, and why monitoring should track dropout alongside diversion and return rates [13], [47], [52].

4.10 Limitations and Research Agenda

This review is limited by database and language scope. Scopus indexing and English-language selection can underrepresent locally produced evidence and gray literature that may contain detailed operational lessons about service design and enforcement [13].

Outcome definitions and measurement methods vary widely. Many studies provide limited detail on service context and do not report burden indicators or completion rates, constraining equity inference. The evidence map in Table 3 is

descriptive and does not substitute for formal quality appraisal [18].

Future research should prioritize testing mechanisms and safeguards. This includes evaluating how allowance structures, return-point density, cash versus digital redemption, building-level container provision, and rule simplification affect both participation and burden distribution over time. Longer follow-up is needed to capture dropout dynamics and maintenance effects that often drive equity outcomes [16], [20].

5. CONCLUSION

This systematic literature review of 55 studies shows that equity in household food and packaging waste reduction is shaped by interaction among household capabilities, service design conditions, measurement choices, and policy instruments. Household characteristics matter, but many apparent behavioral differences are mediated by feasibility conditions such as coverage, proximity, reliability, and rule clarity [22], [27].

The most consistent pathway to narrow participation gaps is access-first service improvement. Stable pickup schedules, clean and safe sites, simplified rules, and container provision reduce participation cost and enable broader compliance. Digital tools can support participation, but only when low-technology pathways and privacy safeguards are designed as core features [32], [38].

Equity-credible evaluation requires deliberate measurement design. Self-report methods should be paired with validation and neutral framing, while direct methods should be burden-mitigated and transparently reported in terms of recruitment, dropout, and representativeness. Smart sensing can improve temporal resolution, but equitable deployment and governance are essential to prevent new forms of exclusion [19], [42].

Packaging instruments such as pay-as-you-throw, deposit-return systems, and extended producer responsibility require explicit safeguards. Without allowances and accessible infrastructure, these instruments can become regressive and shift burdens onto households least able to comply. Equity metrics should be embedded into performance management alongside diversion and waste reduction targets [4], [11].

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