Journal of Sustainable Development and Green Technology

♦ ISSN: 2836-5399 Vol: 06, No. 02, 2026 ♦ PP. 38–52

♦ Article DOI: https://doi.org/10.54216/JSDGT.060205



FULL LENGTH ARTICLE

Designing Robust Household Food Waste Targets for Sustainable Consumption Policy

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Received: February 06, 2026 Revised: March 14, 2026 Accepted: April 18, 2026 ⋆ Corresponding author

ABSTRACT

Decisions must be made both about how food-waste target reductions are allocated and what evidence is used to demonstrate progress. This study develops a bounded policy-accounting framework using the United Nations Environment Programme Food Waste Index 2024. The core sample comprises 38 economies with high-confidence or Eurostat-tagged estimates, representing 82.03 million tonnes of annual household waste. A 50% aggregate reduction is allocated using proportional reductions, equal kilogram reductions, and an explicitly assumed 60% reducibility cap. For the same objective of 41.01 million tonnes, country reduction rates are 50%, 30.43–60%, and 0–60%, respectively. Rankings by per-capita waste and total waste mass share only one economy among their respective top-five lists, and have a Spearman correlation of 0.222. A measured 50% reduction under measurement-error bounds of ±10% corresponds to a true reduction of 38.89–59.09%. Country distinctions also become less clear as error bounds widen. The results support separating rules for allocating physical targets, choosing interventions, and certifying progress. The selected allocation principle should be made public, tested against waste-composition data, and accompanied by comparable measurements before progress toward targets is certified.

Keywords: Household food waste ▪ Sustainable consumption ▪ Policy targets ▪ Resource efficiency ▪ Measurement uncertainty ▪ SDG 12.3

1. INTRODUCTION

With a collective food-waste target, several decisions remain. Governments need to establish a baseline, identify what constitutes waste, and determine the reduction required in each jurisdiction. These choices can substantially change priorities. An economy with high per-person waste may contribute little to the total stream, while a populous economy with moderate per-person waste may be a large contributor. A sound target should expose both quantities.

Food waste has environmental costs that arise before waste treatment. Zhu et al. [1] estimate emissions associated with food loss and waste across food value chains and treatment, while Gatto and Chepeliev [2] examine related nutritional and environmental pressures. These findings establish the importance of prevention in sustainability policy. Turning that context into national obligations requires determining which physical reductions are feasible and how to share them.

Implementation adds further variation. Vittuari et al. [3] connect household behaviour with motivation, opportunity, and ability, while Casonato et al. [4] assess evidence for consumer prevention measures. Different intervention strategies may be needed to achieve the same percentage commitment in different settings. Information on household practices and programme delivery is therefore needed to determine how a desired reduction can be realised.

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Verification also matters. A reported decrease depends on the comparability of baseline and follow-up measurements. The allocation objective can be held constant while comparing burden-sharing rules. Let a_i be the assigned reduction in kg per person and v_i the conversion weight from kg per person to national tonnes. Every allocation must satisfy the same aggregate accounting requirement:

$$\sum_i v_i a_i = B = \tau \sum_i T_i, \tag{1}$$

where B is the common reduction requirement and T_i is the published annual waste mass. Holding B fixed prevents one allocation from appearing more efficient merely because it requires a larger total reduction. Additional cost, household-constraint, and avoidable-waste information would be needed to assess intervention costs.

The analysis uses the Food Waste Index Report 2024, published in March 2024, as a fixed evidence base and includes evidence available through 31 March 2025 [5]. It asks three questions: How do country priorities change when expressed in kg per capita rather than tonnes? How do alternative allocation principles distribute a shared reduction requirement? What measurement error can be accommodated before an observed improvement changes interpretation?

This study links target allocation and progress verification in one numerical framework. It compares constrained allocations based on published country estimates and calculates exact measurement-error bounds for interpreting progress. The cross-section cannot identify existing legislation or predict national waste in 2030. Instead, it shows what a proposed target requires, how the burden changes under alternative rules, and how much measurement precision is needed to evaluate delivery.

2. ANALYTICAL FRAMEWORK

2.1 Waste Prevention and Sustainable Consumption

Waste prevention means avoiding the provision of food that is not needed, through decisions about purchasing, storage, preparation, and consumption. A clear distinction between collection and treatment is important: treatment can improve while generation remains unchanged, as emphasized in policy assessment by Kakadellis et al. [6]. Household food waste is the waste generated by households. Separately collected tonnage is a service indicator and should be reported alongside, not in place of, the waste-generation outcome.

The measured household stream includes food and associated inedible parts. Preventable mass depends on composition and local conditions, whereas total mass is an accounting quantity. Let w_i be the published household estimate and e_i the share considered reducible in a policy scenario. An assignment is feasible only when

$$0 \le a_i \le e_i w_i, \qquad 0 \le e_i \le 1. \tag{2}$$

The cap restricts an allocation to the assumed prevention potential. The comparison applies the assigned reduction and leaves other waste unchanged. The annex does not report a common edible or preventable fraction; thus e_i is a scenario assumption. If a common cap e is used across economies, a collective target fraction τ is feasible if and only if $e \ge \tau$. When $e = \tau = 0.50$, there is no flexibility to redistribute the requirement.

Feasible reductions depend on local practice. Aloysius et al. [7] treat leftover management as a distinct behavioural issue, while Chia et al. [8] report cross-country differences in prevention barriers. Local applications therefore require composition audits and evidence about achievable prevention. Treating e_i as a universal technical constant would conceal variation that programme design should address.

2.2 Alternative Principles for Distributing a Common Target

Three allocation principles are compared. Proportional allocation assigns every economy the same fractional reduction τ. Equal-kilogram allocation assigns a uniform per-person reduction d up to the point where the cap binds. The common-ceiling rule assigns reductions toward a common residual intensity c, subject to the same cap:

$$\begin{aligned} a_{i,P} &= \tau w_i, \\ a_{i,A} &= \min(e_i w_i, d), \\ a_{i,C} &= \min(e_i w_i, \max(w_i - c, 0)). \end{aligned} \tag{3}$$

The parameters d and c are selected to satisfy Equation 1. Each rule expresses a different burden-sharing principle. The ceiling imposes higher relative requirements on economies with higher starting intensities, while equal-kilogram allocation limits absolute per-person reductions. Proportional allocation preserves the relative difference in residual intensities. These are physical allocation rules; assessing fairness also requires information about income, food security, household composition, and administrative capacity.

The parameter c is a ceiling. No reduction is applied to economies below c. An economy with a binding cap may remain above c after its assigned reduction. The rule is therefore capped convergence with specific exceptions, not a residual standard enforced across all economies.

Figure 1 shows the sequence of decisions. The evidence screen establishes the accounting sample. Allocation then compares alternative obligations at a fixed B. A measurement audit determines how subsequent progress should be interpreted. Composition evidence constrains the sequence throughout: an infeasible prevention requirement cannot be made feasible by changing the allocation formula.

2.3 Choosing Interventions and Interpreting Their Effects

An assigned reduction a_i is an obligation, whereas an intervention effect is a change a programme can create. Cooper et al. [9] examine ways to use food already at home; Boulet et al. [10] rank behaviours by potential impact and likelihood of adoption. This evidence can inform delivery, but country-level application requires comparable waste composition, household coverage, and implementation conditions. Reviews of food-waste nudges and European consumer reduction targets also show that intervention effects differ across types and settings [11, 12]. A numerical obligation should therefore be accompanied by a delivery hypothesis and an evaluation design. Requiring a_i kilograms of reduction states the goal; it does not prove that information campaigns, labels, or collection changes will deliver it.

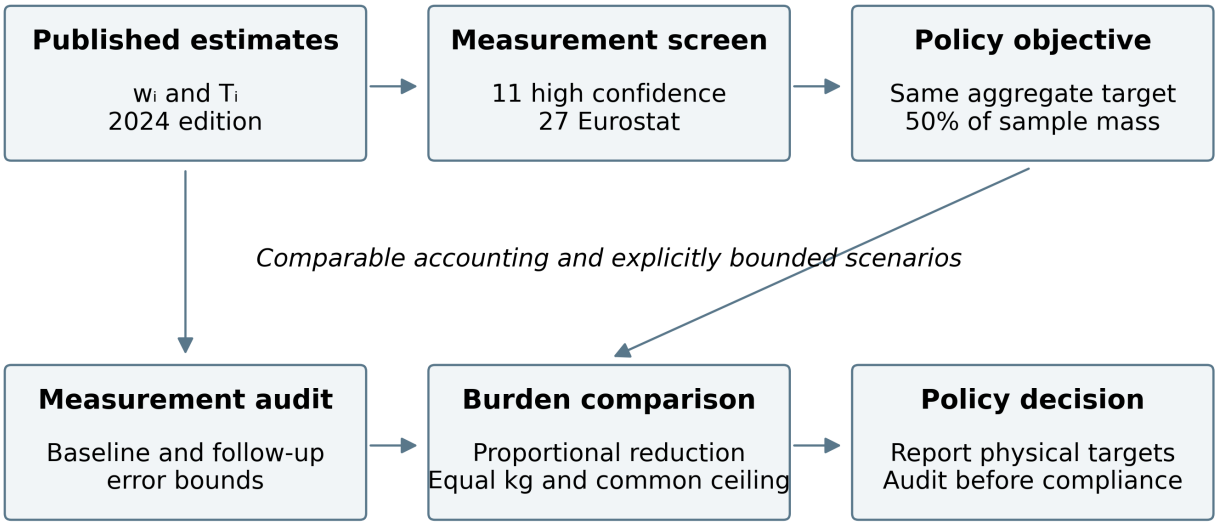


Figure 1. Framework for target allocation and progress verification.

Source: Author framework. Published inputs and scenario restrictions enter separate stages. The allocation objective is held constant; measurement bounds govern later interpretation of progress.

The implementation identity $a_i = k_i p_i$ makes the missing evidence explicit: k_i is the mass exposed to an intervention per person, and p_i is the average share prevented within that mass. A small programme may affect participants but reach few people nationally. Conversely, a programme may reach many people but have little effect on disposal decisions. Both impact and reach must be measured before intervention effects can be compared with national assignments.

3. DATA AND METHODS

3.1 Published Evidence and Sample Construction

All numerical inputs come from Annex 3 of the Food Waste Index Report 2024, pages 166–172 [5]. The annex contains 233 country or territory entries: 11 high-confidence estimates, 27 Eurostat entries, 55 medium-confidence estimates, 98 low-confidence estimates, and 42 very-low-confidence estimates. The main sample retains the first two groups, giving 38 economies. The Eurostat designation is retained as a source type and is not recoded as a high-confidence rating.

The main selection prioritises better-supported measurements and official reports while preserving distinctions between sources. It does not remove methodological differences: measurement choices affect reported waste ratios [13]. The sample also has limited geographic coverage. A sensitivity test adds the 55 medium-confidence estimates, giving 93 economies. Low- and very-low-confidence entries are excluded from the primary calculations because they would add less-supported estimates to the burden comparison.

The annex reports kilograms per person, annual tonnes, country identifiers, and evidence designations. The estimates come from studies conducted at different times rather than synchronized national surveys, so they serve as a fixed accounting baseline, not as policy-performance changes or time trends. No database update or outcome after March 2025 is included.

Table 1. Published evidence designations and household estimates

Designation	Entries	Mean (kg)	Median (kg)	Min.	Max.
High confidence	11	75.82	79.0	19	105
Eurostat	27	70.67	69.0	26	124
Medium confidence	55	95.85	89.0	18	207
Low confidence	98	88.55	89.0	67	104
Very low confidence	42	87.48	87.5	60	140

Source: UNEP (2024), Annex 3; author calculations. The core sample comprises high-confidence and Eurostat entries. Descriptive means in excluded groups include published extrapolations. Designations are not numerical confidence intervals.

The two measures of mass have different precision. Let w_i be kilograms per person and T_i annual tonnes. Define a conversion weight $v_i = T_i/w_i$, expressed in tonnes per kilogram and reflecting an implied population divided by 1,000. It is not based on an observed population series. Using these weights reconciles the scenario totals with published totals, apart from minor rounding differences:

$$v_i = \frac{T_i}{w_i}, \qquad W = \sum_i T_i = \sum_i w_i v_i. \tag{4}$$

The weight factor W represents the total; the unweighted average gives each economy equal importance. The two summaries answer different questions. The calculated v_i values do not add population detail beyond the rounded source data, and reconciliation does not imply that actual waste was measured precisely.

3.2 Allocation Calculations and Burden Summaries

The central target is $\tau = 0.50$ of core-sample mass, with conversion weights fixed. One-dimensional root finding selects

d and c. Allocation functions are continuous and monotonic; numerical checks ensure every assignment lies between zero and $e_i w_i$ and total assigned tonnes equal B within tolerance. When $e = \tau$, the parameters are not unique; the analysis reports the smallest fully saturating d and largest fully saturating c.

Relative burden is $r_i = a_i / w_i$. The analysis reports its minimum, maximum, and standard deviation across economies, along with the number at the cap and the number assigned zero. The standard deviation is descriptive for the 38-economy accounting sample, not a standard error or estimate of a population parameter. A person-weighted mean burden would require the corresponding conversion weights and would answer a different question.

With the sample and weights fixed, all feasible rules produce the same weighted residual intensity, $(1-\tau)W$. Differences among rules therefore concern how residuals are distributed across economies, not an aggregate physical advantage. This identity checks the calculations and prevents a flatter residual profile from being called more effective by itself.

3.3 Priority Rankings and Bounded Comparisons

Countries are ranked separately by kilograms per person and by tonnes. Spearman correlation summarises agreement between the orderings, with tied intensity values assigned ranks for the correlation. Tables use competition ranks to preserve ties. The overlap between the five highest-intensity economies and the five largest totals compares the priority lists. No significance test is attached to this selected accounting sample.

A rank envelope measures how far an intensity rank can move when measurements are uncertain. If published value w_i has bounded multiplicative error η relative to its underlying value, its admissible interval is $[w_i/(1+\eta), w_i/(1-\eta)]$. Economy i is clearly higher than economy j only when its lowest admissible value exceeds the highest admissible value of j:

$$w_i(1-\eta) > w_j(1+\eta). \tag{5}$$

Each economy's highest and lowest possible ranks are determined by intervals that are definitely higher or lower. These are worst-case limits, not probability ranges; no error distribution is specified. Under the assumption of independent errors between economies, pairwise separation is assessed for $n(n-1)/2 = 703$ pairs. Ties are not separated even when $\eta = 0$. Lack of separation means a clear ranking requires accuracy beyond the specified bound.

3.4 Exact Bounds for Progress Verification

For two measurement rounds, let observed baseline and follow-up be x_0 and x_1, with $x_t = z_t(1+\varepsilon_t)$, where z_t is underlying intensity and $|\varepsilon_t| \le \eta < 1$. If observed proportional reduction is $\widehat{R} = 1 - x_1/x_0$, the true reduction is

$$R = 1 - (1-\widehat{R})\frac{1+\varepsilon_0}{1+\varepsilon_1}. \tag{6}$$

The minimum and maximum occur at endpoints of the error ranges; no sampling distribution is needed. Allowing errors to differ between rounds accommodates changes in coverage, classification, or measurement. If both rounds have the same multiplicative error, it cancels in the ratio and the measured decrease is unchanged. The worst case is therefore both a comparability and a precision issue. With a common bound η,

$$\begin{aligned} R_{\min} &= 1 - (1-\widehat{R})\frac{1+\eta}{1-\eta}, \\ R_{\max} &= 1 - (1-\widehat{R})\frac{1-\eta}{1+\eta}. \end{aligned} \tag{7}$$

Inverting the lower bound gives the measured reduction required to assure a true reduction of at least τ:

$$\widehat{R}_{\text{required}} = 1 - (1-\tau)\frac{1-\eta}{1+\eta}. \tag{8}$$

The limit depends on η and on conceptual coverage in both rounds. It is a tolerance check, not a change to the sustainability goal. Bridge studies and steady sampling can reduce the allowed error range. The calculation shows the effect of a chosen tolerance; the Food Waste Index does not report its value.

4. RESULTS

4.1 Baseline Quantities and Concentration

The 38-economy core contains 82.027 million tonnes of annual household waste. The mean is 72.16 kg per person, the median is 72 kg, and the interquartile range is 61–85.5 kg. The sample standard deviation is 21.27 kg. Reconciled weighted intensity is 74.06 kg per person, slightly above the unweighted mean. These are summaries of the selected sample, not estimates for the world.

Published intensity ranges from 19 kg per person in Bhutan to 124 kg in Portugal, a ratio of 6.53. This spread reflects differences in waste composition, measurement, and household practices; it is not a ranking of policy performance. Even countries near the bottom of the intensity distribution may have preventable edible material, making composition data important.

Figure 2 shows why population-equivalent scale matters for a target. The United States has the largest core total at 24.72 million tonnes, followed by Japan at 7.40 million, Germany at 6.50 million, Italy at 6.32 million, and the United Kingdom at 5.10 million tonnes. These five economies account for 60.99% of the core total; they are not the five largest per-person estimates.

Concentration matters for the scale of the work. Halving waste in the five largest contributors would remove 30.50% of the core baseline: $0.50 \times 0.6099 = 0.3050$. This would not reach the 50% goal. Programmes in high-intensity economies may have substantial local value but contribute fewer tonnes to the aggregate.

4.2 Priority Lists Under Alternative Metrics

The rank correlation between waste intensity and total mass is 0.222. Only Italy appears in both top-five lists. The highest-intensity list comprises Portugal, Italy, Saudi Arabia, Australia, and Qatar; together they account for 17.33% of core tonnes. The five largest totals account for 60.99%, a difference of 43.66 percentage points of sample mass. This gap follows from the different metrics used to construct the lists.

Table 2. Core sample of household waste estimates and descriptive ranks

Economy	Source	kg per person	Tonnes per year	Intensity rank	Mass rank
Australia	H	98	2,559,065	4	11
Austria	E	83	742,020	12	17
Belgium	E	71	827,860	20	16
Bhutan	H	19	15,072	38	38
Bulgaria	E	26	176,280	37	31
Canada	H	79	3,019,925	14	8
Croatia	E	53	213,590	33	30
Cyprus	E	71	88,750	20	33
Czechia	E	69	723,810	22	18
Denmark	E	79	464,520	14	21
Estonia	E	61	81,130	25	34
Finland	E	53	293,620	33	25
France	E	61	3,942,430	25	6
Germany	E	78	6,502,860	16	3
Ghana	H	84	2,812,571	11	10
Greece	E	87	903,930	8	15
Hungary	E	66	658,020	23	19
Ireland	E	48	240,960	35	28
Italy	E	107	6,317,280	2	4
Jamaica	H	86	243,364	9	27
Japan	H	60	7,398,006	30	2
Latvia	E	82	151,700	13	32
Lithuania	E	86	236,500	9	29
Luxembourg	E	91	59,150	7	36
Malta	E	92	48,760	6	37
Netherlands	E	59	1,036,040	32	14
New Zealand	H	61	316,590	25	24
Norway	E	78	423,540	16	22
Poland	E	60	2,391,600	30	12
Portugal	E	124	1,273,480	1	13
Qatar	H	93	250,830	5	26
Saudi Arabia	H	105	3,818,681	3	7
Slovakia	E	65	366,600	24	23
Slovenia	E	36	76,320	36	35
Spain	E	61	2,895,272	25	9
Sweden	E	61	643,550	25	20
United Kingdom	H	76	5,097,005	18	5
United States of America	H	73	24,716,539	19	1

Source: UNEP (2024), Annex 3, printed pp. 166–172; ranks are author calculations. H: high-confidence estimate. E: Eurostat-tagged estimate. Intensity ranks use competition ranking, retaining ties. Estimates include food and associated inedible parts; underlying measurement dates vary.

Portugal and the United States illustrate the difference. Portugal has an intensity of 124 kg per person and a total of 1.27 million tonnes annually. The United States produces 73 kg per person and 24.72 million tonnes, 19.41 times Portugal's total. Portugal stands out by per-person waste, while the United States is much larger by total waste. Which matters depends on the policy goal, not on a conflict between the numbers.

With a 10% error margin, only 432 of 703 country pairs remain clearly separated (61.45%). With a 20% margin, this falls to 220 pairs (31.29%). At zero error, 16 pairs share the same rounded intensity. The problem is concentrated among close values: small differences can shift ranks substantially, so exact positions may imply more precision than policy decisions require.

Figure 3 retains the rankings while showing how far each country can move within the error bounds. Shaded areas widen where many countries have similar intensities. These comparisons identify where more data are needed before public rankings or penalties are decided. The envelopes do not assign probabilities to rank positions; they show uncertainty under specified bounds.

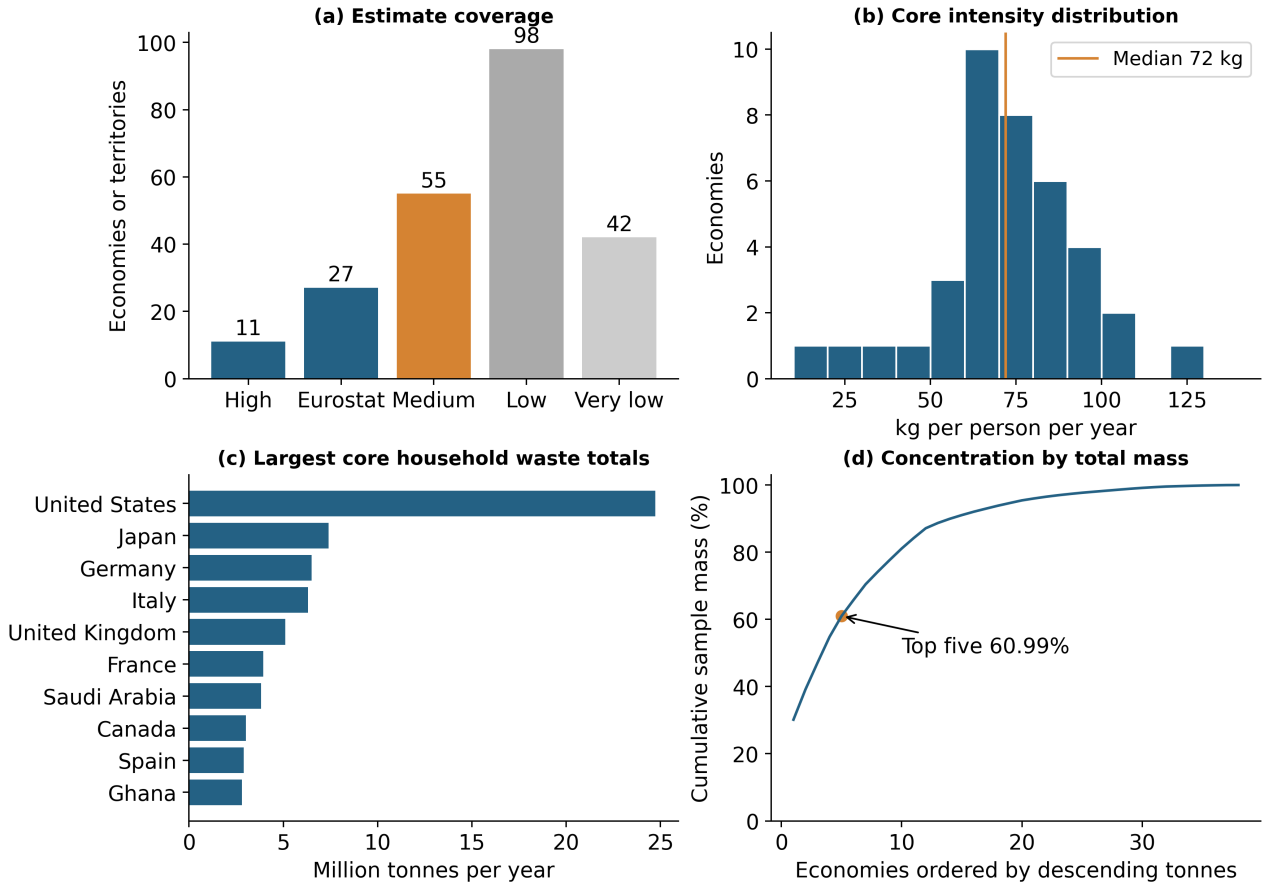


Figure 2. Evidence coverage and the concentration of household waste.

Source: UNEP (2024), Annex 3; author calculations. Panel (a) covers 233 published entries; panels (b)–(d) use the 38-economy core. Core totals are not global estimates. Tonnes are published annual estimates rather than contemporaneous survey observations.

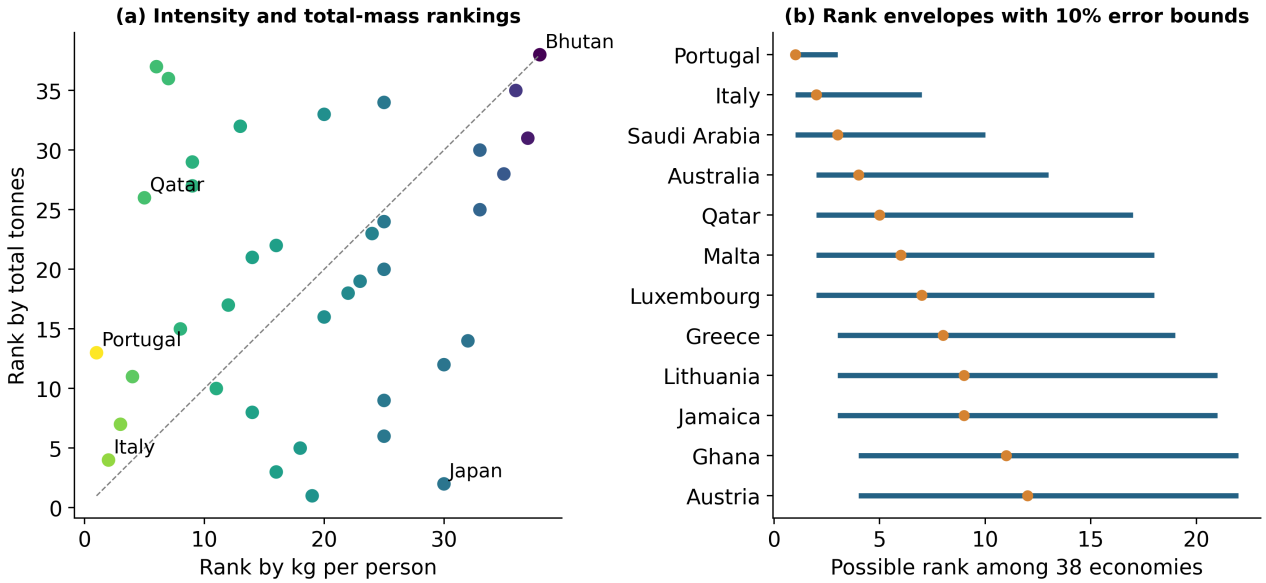


Figure 3. Priority metrics and bounded intensity rankings.

Note: Author calculations from the core sample. Panel (a) contrasts competition ranks; colour represents published intensity from lower (purple) to higher (yellow). The dashed line indicates equal rank. Panel (b) shows feasible rank envelopes for 10% error bounds, with published ranks in orange. Envelopes are not probabilities.

4.3 Allocating an Identical Collective Reduction

The common 50% requirement is 41.01361 million tonnes. With a 60% reducibility cap, all three rules reach this total within tolerance. Proportional allocation assigns every country a 50% reduction. Equal-kilogram allocation gives an uncapped reduction $d = 37.7275$ kg per person; the ceiling rule uses $c = 36.3875$ kg per person.

Although d and c are numerically close, their allocations differ. Under equal kilograms, reductions range from 30.43% to 60%, with 14 countries at the cap. Under the ceiling rule, reductions range from 0% to 60%, with seven at the cap and three assigned zero. The country standard deviation is 8.72

Table 3. Intensity rank envelopes for the twelve highest published estimates

Economy	kg	Rank	10% best	10% worst	20% best	20% worst
Portugal	124	1	1	3	1	12
Italy	107	2	1	7	1	19
Saudi Arabia	105	3	1	10	1	21
Australia	98	4	2	13	1	23
Qatar	93	5	2	17	1	24
Malta	92	6	2	18	1	24
Luxembourg	91	7	2	18	1	29
Greece	87	8	3	19	1	32
Jamaica	86	9	3	21	1	32
Lithuania	86	9	3	21	1	32
Ghana	84	11	4	22	1	32
Austria	83	12	4	22	1	32

Note: Author calculations. Best and worst positions are feasible envelopes under the bounded multiplicative-error model, not confidence intervals. Baseline ties use competition ranks; envelopes permit strict orderings when intervals overlap.

Table 4. Identical mass objectives and different country burdens

Rule	Reduction (Mt)	Min–max (%)	SD (pp)	At cap / zero	Parameter value
Proportional	41.01361	50.00–50.00	0.00	0 / 0	0.5000
Equal kilograms	41.01361	30.43–60.00	8.72	14 / 0	37.7275
Common ceiling	41.01361	0.00–60.00	16.18	7 / 3	36.3875

Note: Author calculations; $\tau = 0.50$ and $e = 0.60$. SD is the descriptive country standard deviation of relative burdens, not a standard error. Parameters are τ for proportional allocation, d in kg per person for equal kilograms, and c in kg per person for the ceiling rule.

percentage points under equal kilograms and 16.18 under the ceiling, compared with zero under proportional allocation.

Bhutan represents the lower end of the distribution. Its 19 kg estimate produces a proportional assignment of 9.5 kg and a capped equal-kilogram assignment of 11.4 kg; the ceiling rule assigns zero. Portugal's proportional assignment is 62 kg, its equal-kilogram assignment is 37.73 kg (30.43% of its baseline), and its ceiling assignment is capped at 74.4 kg (60%). Equal-kilogram allocation therefore places a larger relative obligation on the lower-intensity economy, while the ceiling rule reverses that pattern.

Figure 4 shows the role of the cap. The equal-kilogram curve rises with baseline intensity until the cap binds and then levels at d. The ceiling curve is zero below c, rises with slope one where convergence is possible, and changes to slope e where the cap binds. These transitions follow from the maximum operators in Equation 3; they are not estimated thresholds.

For all three rules, weighted residual intensity is 37.0278 kg per person. This equality follows from the target and fixed conversion weights; it does not mean all countries reach the same residual. Under the common-ceiling rule, some high-baseline countries remain above c because their caps bind, while economies below c retain their starting intensity. The

Table 5. Selected country assignments under alternative allocation rules

Economy	Baseline / P / A / C (kg)	A / C (%)
Bhutan	19 / 9.50 / 11.40 / 0.00	60.00 / 0.00
Bulgaria	26 / 13.00 / 15.60 / 0.00	60.00 / 0.00
Slovenia	36 / 18.00 / 21.60 / 0.00	60.00 / 0.00
Ireland	48 / 24.00 / 28.80 / 11.61	60.00 / 24.19
Japan	60 / 30.00 / 36.00 / 23.61	60.00 / 39.35
United States of America	73 / 36.50 / 37.73 / 36.61	51.68 / 50.15
Germany	78 / 39.00 / 37.73 / 41.61	48.37 / 53.35
Ghana	84 / 42.00 / 37.73 / 47.61	44.91 / 56.68
Qatar	93 / 46.50 / 37.73 / 55.80	40.57 / 60.00
Australia	98 / 49.00 / 37.73 / 58.80	38.50 / 60.00
Saudi Arabia	105 / 52.50 / 37.73 / 63.00	35.93 / 60.00
Portugal	124 / 62.00 / 37.73 / 74.40	30.43 / 60.00

Note: Author calculations. P: proportional 50% reduction. A: equal kilograms with a 60% cap. C: common residual ceiling with the same cap. Kilograms are per person per year. Country examples illustrate different baseline levels; they are not intervention-effect estimates.

Table 6. Exact measurement bounds for an observed 50% reduction

Error bound (%)	True reduction range (%)	Required measured reduction (%)	Width (pp)
0.0	50.00–50.00	50.00	0.00
2.5	47.44–52.44	52.44	5.00
5.0	44.74–54.76	54.76	10.03
7.5	41.89–56.98	56.98	15.08
10.0	38.89–59.09	59.09	20.20
15.0	32.35–63.04	63.04	30.69
20.0	25.00–66.67	66.67	41.67
25.0	16.67–70.00	70.00	53.33
30.0	7.14–73.08	73.08	65.93

Note: Author calculations using Equations 7–8. The same absolute bound applies separately to each measurement round. The required measured reduction assures a true reduction of at least 50% within the specified error set. Bounds are scenarios, not estimated survey errors.

policy choice is how obligations and exceptions are shared within the same total-mass requirement.

4.4 Verification Under Imperfect Measurement

A measured 50% reduction does not always mean a true 50% reduction when baseline and follow-up errors differ. With a ±5% error bound in each round, the true reduction lies between 44.74% and 54.76%. With a ±10% bound, the interval expands to 38.89–59.09%; with ±20%, it becomes 25.00–66.67%. These are endpoint calculations under the multiplicative model.

The 10% example can be checked directly. If the baseline is overstated by 10% and follow-up understated by 10%, the true remaining fraction is $0.50 \times 1.10/0.90 = 0.6111$, implying a true reduction of 38.89%. Reversing the errors gives $0.50 \times 0.90/1.10 = 0.4091$, or a 59.09% reduction. In both cases the reported decline is 50%. Uncertainty arises from the relationship between the measurements, not from

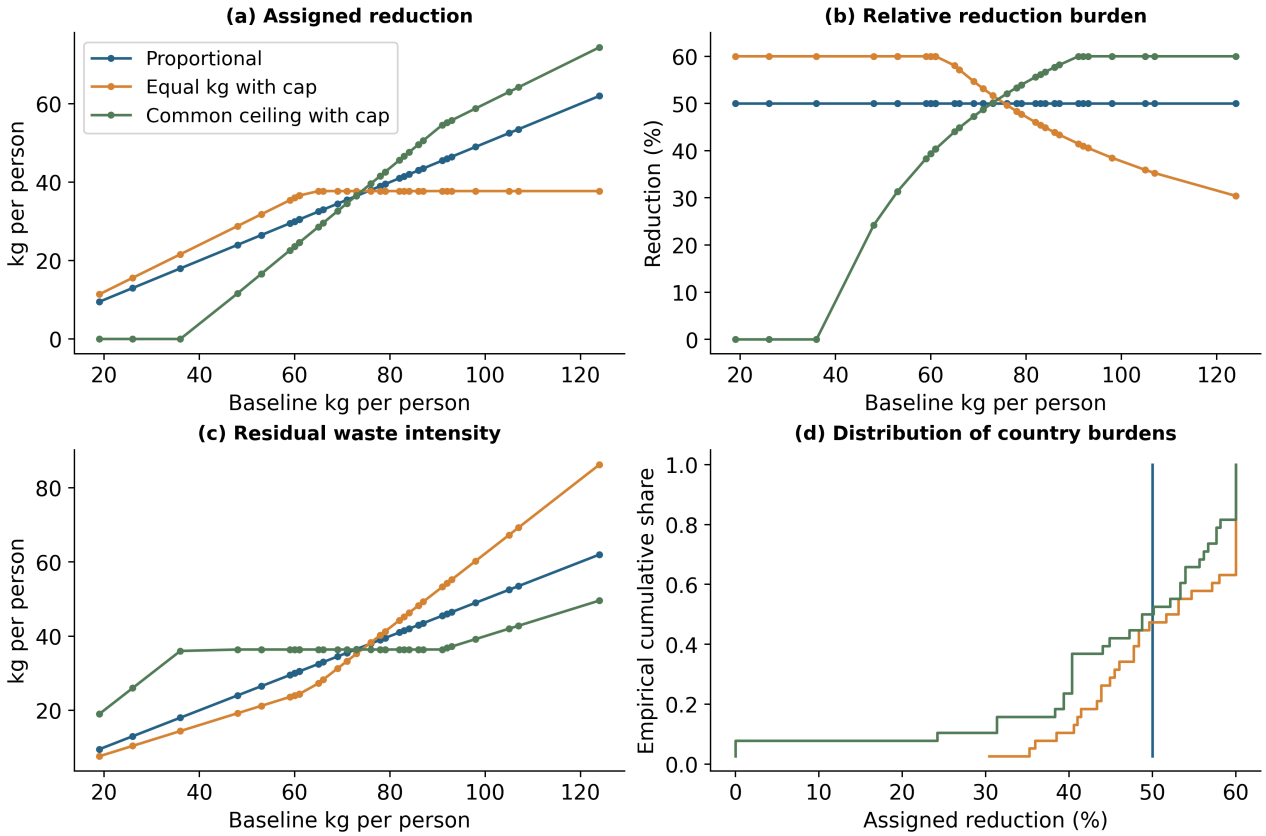


Figure 4. Distribution of assignments at an identical aggregate reduction.

Note: Author calculations; $\tau = 0.50$ and $e = 0.60$. Each rule removes 41.01361 million tonnes. Points represent the 38 core economies, ordered by baseline intensity. Panels (a)–(c) connect points to show assignment functions; panel (d) is the unweighted empirical distribution of relative burdens.

the target itself.

The diagonal in Figure 5 shows multiplicative errors that cancel in the ratio. Moving away from this diagonal changes the implied reduction. This demonstrates why methods, sampling frames, and waste definitions should remain consistent across measurement rounds. A costly new survey does not improve understanding if its scope changes without a link to the baseline. Before using two published figures as a policy-performance ratio, their comparability must be assessed.

To assure at least a 50% reduction, the measured decline must be 54.76% under 5% error bounds, 59.09% under 10% bounds, and 66.67% under 20% bounds. These are certification thresholds conditional on assumed error sets, not predictions or suggested national goals. The gap between the target and measured threshold can be reduced through repeated measurements and aligned methods.

4.5 Sensitivity to Evidence Coverage and Reducibility

Restricting calculations to the 11 high-confidence estimates gives 50.25 million tonnes, weighted intensity 74.48 kg, mean intensity 75.82 kg, and equal-kilogram parameter $d = 37.56$ kg. The 27 Eurostat estimates give 31.78 million tonnes, weighted intensity 73.40 kg, mean intensity 70.67 kg, and $d =$ 38.12 kg. Adding 55 medium-confidence estimates produces a 93-economy sample with 517.03 million tonnes, weighted intensity 76.82 kg, mean intensity 86.17 kg, and $d = 42.42$ kg.

Adding medium-confidence estimates increases the total by more than sixfold but raises weighted intensity by 3.73%. Similar per-person averages can therefore conceal different overall exposure. The extension changes both coverage and evidence support; it tests sensitivity to sample selection but does not imply that expanded estimates are as reliable as the core estimates.

Table 7. Sensitivity to the evidence groups included in the sample

Sample	N	Mass (Mt)	Weighted / mean (kg)	d / c (kg)
Core	38	82.027	74.06, 72.16	37.73, 36.39
High only	11	50.248	74.48, 75.82	37.56, 36.90
Eurostat only	27	31.780	73.40, 70.67	38.12, 35.52
Core plus medium	93	517.028	76.82, 86.17	42.42, 36.21

Note: Author calculations, $\tau = 0.50$, $e = 0.60$. Weighted kg uses reconciled conversion weights; mean kg is the unweighted country average. "Core plus medium" includes all 55 medium-confidence entries and is a sensitivity sample.

Changing the reducibility cap changes the scope for burden sharing. At $e = 0.50$, every country must provide half its baseline, so all three assignment vectors are identical. Larger caps allow the kilogram and ceiling rules to diverge. At the boundary, the assignment vector is unique although d and c are not; the table uses the smallest saturating d and largest fully saturating c. Above the boundary, parameters and burden distribution change. This is an algebraic feasibility result, not evidence that higher caps are technically achievable.

Figure 6 separates changes in the sample from changes in

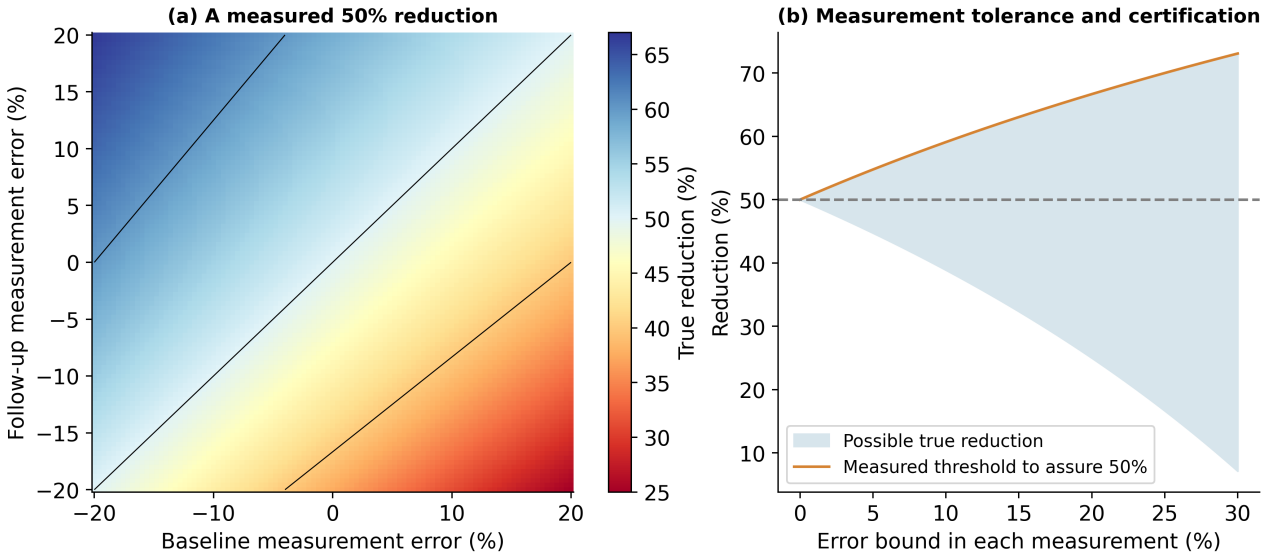


Figure 5. Measurement comparability and conservative verification thresholds.

Note: Deterministic calculations using Equations 6–8. Panel (a) conditions on an observed 50% reduction and varies baseline and follow-up errors separately. In panel (b), shading gives feasible true reductions, while the orange line gives the measured reduction needed to assure at least 50%. These are assumed error scenarios.

Table 8. Sensitivity to the assumed maximum reducible share

Cap (%)	d (kg)	c (kg)	A / C SD (pp)	A / C at cap
50	62.00	9.50	0.00, 0.00	38, 38
55	39.08	35.48	6.37, 15.01	19, 15
60	37.73	36.39	8.72, 16.18	14, 7
65	37.25	37.03	10.17, 16.66	6, 2
70	37.20	37.11	11.30, 16.84	6, 1
80	37.16	37.11	13.07, 16.85	3, 0
90	37.14	37.11	14.83, 16.85	3, 0
100	37.11	37.11	16.85, 16.85	3, 0

Note: Author calculations for the 38-economy core and 50% aggregate target. At $e = 0.50$, all assignments equal half the baseline; d and c are not unique. The boundary row reports the smallest fully saturating $d = 62$ kg and largest fully saturating $c = 9.5$ kg. A and C denote equal-kilogram and ceiling rules.

planning assumptions. Sample inclusion changes the amounts entering B; the cap limits the reduction that can be assigned; measurement tolerance affects the ability to distinguish countries. Adding countries cannot establish a preventable share, and a strict cap cannot compensate for inaccurate baseline measurements.

The sensitivity checks support two points: burden sharing changes when the cap exceeds the aggregate goal, and country ordering depends on both the chosen metric and measurement accuracy. The values of d and c depend on the sample. An organisation applying the framework to another set of countries must recalculate them using that sample's baseline and approved caps.

5. DISCUSSION

5.1 Implications for Sustainable Consumption Policy

The allocation principle determines how a collective commitment becomes an obligation. Proportional reductions preserve relative differences. Equal kilograms limit absolute per-person demands. The capped ceiling focuses effort on higher starting intensities. These differences matter for implementation, but the data do not show affordability or administrative capacity. Dispersion in r_i alone cannot determine fairness.

National assignments conceal household-level differences. Storage facilities, shopping patterns, and cooking responsibilities vary within countries. Shigetomi et al. [14] show that demographic composition and food categories affect household waste and associated emissions in Japan. Local evidence is needed to translate national kilogram requirements into measures households can realistically adopt.

Service provision also distinguishes prevention from improved waste treatment. Landells et al. [15] identify capacity, contamination, and cost concerns in council food-organics programmes. More separately collected material can indicate service coverage even when waste generation is unchanged. Evaluations should track both indicators and state which outcome a programme intends to change.

In practice, an authority would specify participating jurisdictions, the waste boundary, and τ before assigning reductions. Composition studies would support e_i. The selected allocation rule would create obligations in kg per person and tonnes. Delivery measures could then be evaluated against those obligations. Repeated measurement should be designed from the outset, with a documented link between baseline and follow-up.

Table 9 shows national mass implications. For each economy, the assigned reduction in tonnes is $v_i a_i$. Differences from proportional allocation show how much of the common requirement moves between countries. Summed signed differences equal zero; half the sum of absolute differences measures reassigned mass without counting transfers twice.

Equal-kilogram allocation moves 2.527 million tonnes, or 6.16% of the target, relative to proportional allocation. Twenty economies receive larger obligations and eighteen receive smaller ones. Japan receives the largest increase (739.80 thousand tonnes), while Italy receives the largest

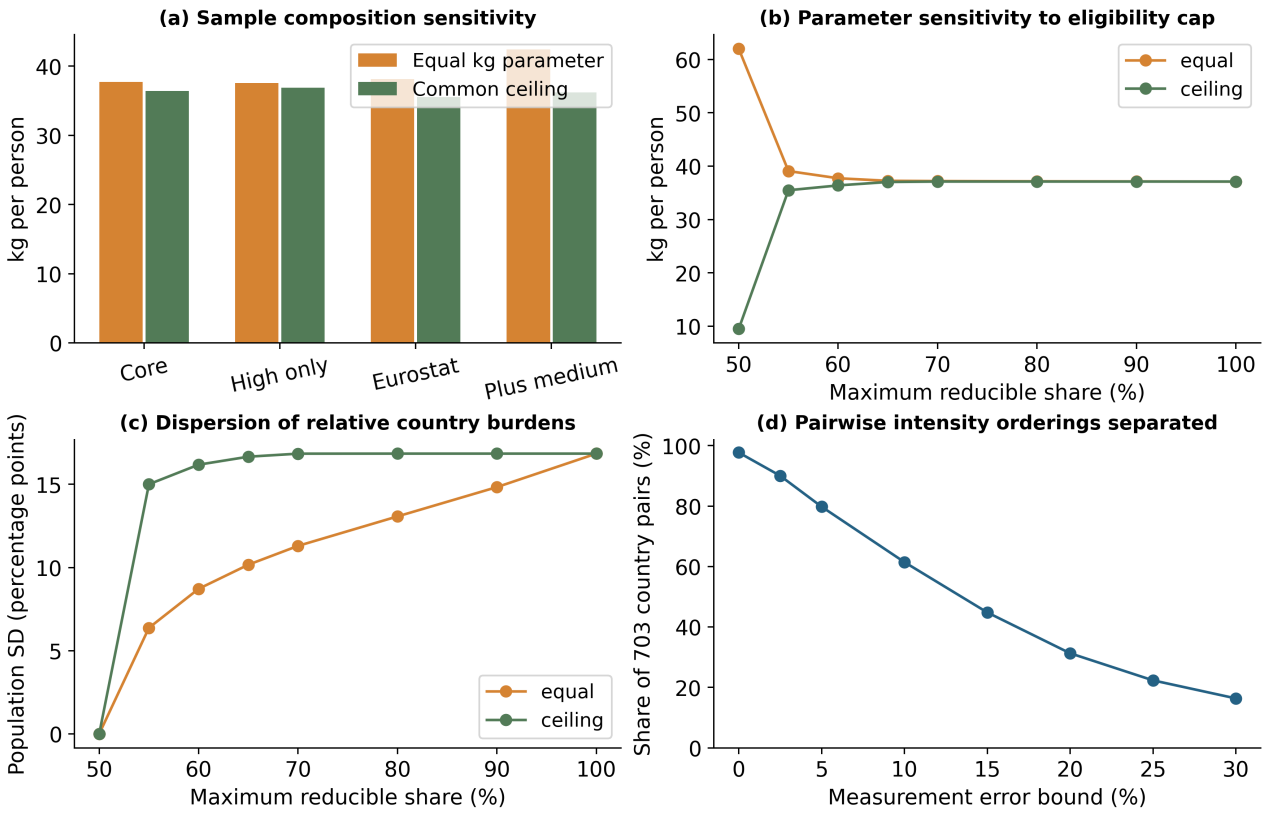


Figure 6. Sensitivity of allocation and comparison to analytical assumptions.

Note: Author calculations. Panel (a) varies sample inclusion at $e = 0.60$. Panels (b)–(c) vary the reducibility cap at a fixed 50% target in the core. The 50% cap uses canonical boundary parameters specified in Table 8. Panel (d) counts strict separations among 703 core country pairs; ties remain unseparated.

decrease (931.21 thousand tonnes). The ceiling rule moves 2.301 million tonnes, or 5.61% of the target, with increases for nineteen economies and decreases for nineteen. Italy's obligation rises by 631.73 thousand tonnes and Japan's falls by 787.58 thousand tonnes.

These transfers identify where implementation plans would need to change if an authority changed its burden principle. They are assigned prevention tonnes, not fiscal transfers or measured household responses. Equal-kilogram allocation raises obligations in lower-intensity economies; the ceiling gives more weight to higher starting intensities. The country-level accounting makes these consequences visible even though each rule delivers the same aggregate requirement by construction.

5.2 Environmental Interpretation and Policy Coherence

A mass target supports material accounting. Environmental benefit depends on the food prevented and production displaced. A composition-sensitive calculation would require

$$\Delta H = \sum_i \sum_j \Delta m_{ij} f_{ij} - L, \tag{9}$$

where Δm_{ij} is prevented mass in food category j, f_{ij} the relevant life-cycle impact factor, and L the net offset from substitution, leakage, or rebound. Country totals do not report these components separately. Applying one emissions factor to allocated tonnes would therefore produce an unsupported estimate. This analysis measures physical waste reduction, not environmental impact.

Zhu et al. [1] and Gatto and Chepeliev [2] show why supply-chain coverage and food composition matter. The mass target is one component of sustainability governance: preventing a smaller amount of high-impact food can have a different environmental effect from preventing a larger amount of low-impact food. Where impact reduction is the main goal, local evaluations should track food composition while maintaining a consistent total-mass series.

Food safety and adequate nutrition must remain constraints during implementation. Meeting a waste target should not mean households eat unsafe food or less than they need. Reclassifying material should not count as prevention unless actual waste generation falls. A stable mass boundary is necessary to preserve the meaning of the reduction ratio.

Physical delivery must precede the prevented mass entering Equation 9. Let T be baseline mass, e the eligible share, and u the fraction of eligible mass actually prevented. Effective delivery combines programme reach with effectiveness among those reached. Under this definition,

$$M = ueT, \qquad u_{\text{required}} = \frac{\tau}{e}, \qquad G_{0.80} = \max(\tau - 0.80e, 0)T. \tag{10}$$

Table 10 varies the target and eligible share while holding the published 82.02722-million-tonne baseline fixed. Required effective delivery τ/e exceeds 100% wherever the target is infeasible even with full delivery. The last column reports the remaining shortfall at 80% delivery. These scenarios test consistency; they do not estimate eligibility, adoption, or environmental impacts.

For a 50% target and $e = 0.60$, 83.33% of eligible mass must actually be prevented. An 80% delivery rate removes 39.373 million tonnes, leaving a 1.641-million-tonne shortfall.

Table 9. National mass obligations and reallocation under a common target

Economy	P (kt)	A (kt)	C (kt)	A−P (kt)	C−P (kt)	Baseline share (%)
Australia	1279.53	985.17	1535.44	-294.36	255.91	3.12
Austria	371.01	337.28	416.72	-33.73	45.71	0.90
Belgium	413.93	439.90	403.58	25.97	-10.35	1.01
Bhutan	7.54	9.04	0.00	1.51	-7.54	0.02
Bulgaria	88.14	105.77	0.00	17.63	-88.14	0.21
Canada	1509.96	1442.20	1628.94	-67.76	118.98	3.68
Croatia	106.80	128.15	66.95	21.36	-39.85	0.26
Cyprus	44.38	47.16	43.27	2.78	-1.11	0.11
Czechia	361.90	395.76	342.11	33.86	-19.80	0.88
Denmark	232.26	221.84	250.56	-10.42	18.30	0.57
Estonia	40.56	48.68	32.73	8.11	-7.83	0.10
Finland	146.81	176.17	92.03	29.36	-54.78	0.36
France	1971.21	2365.46	1590.71	394.24	-380.51	4.81
Germany	3251.43	3145.34	3469.23	-106.09	217.80	7.93
Ghana	1406.29	1263.23	1594.21	-143.06	187.92	3.43
Greece	451.96	391.99	525.86	-59.98	73.90	1.10
Hungary	329.01	376.14	295.24	47.13	-33.77	0.80
Ireland	120.48	144.58	58.29	24.10	-62.19	0.29
Italy	3158.64	2227.43	3790.37	-931.21	631.73	7.70
Jamaica	121.68	106.76	140.39	-14.92	18.71	0.30
Japan	3699.00	4438.80	2911.42	739.80	-787.58	9.02
Latvia	75.85	69.80	84.38	-6.05	8.53	0.18
Lithuania	118.25	103.75	136.43	-14.50	18.18	0.29
Luxembourg	29.57	24.52	35.49	-5.05	5.92	0.07
Malta	24.38	20.00	29.26	-4.38	4.88	0.06
Netherlands	518.02	621.62	397.08	103.60	-120.94	1.26
New Zealand	158.29	189.95	127.74	31.66	-30.56	0.39
Norway	211.77	204.86	225.96	-6.91	14.19	0.52
Poland	1195.80	1434.96	941.19	239.16	-254.61	2.92
Portugal	636.74	387.46	764.09	-249.28	127.35	1.55
Qatar	125.42	101.75	150.50	-23.66	25.08	0.31
Saudi Arabia	1909.34	1372.09	2291.21	-537.25	381.87	4.66
Slovakia	183.30	212.78	161.37	29.48	-21.93	0.45
Slovenia	38.16	45.79	0.00	7.63	-38.16	0.09
Spain	1447.64	1737.16	1168.19	289.53	-279.44	3.53
Sweden	321.77	386.13	259.66	64.36	-62.11	0.78
United Kingdom	2548.50	2530.23	2656.65	-18.28	108.14	6.21
United States of America	12358.27	12773.88	12396.36	415.61	38.09	30.13
Core total	41013.61	41013.61	41013.61	0.00	0.00	100.00

Note: Author calculations from the fixed 38-economy core; $\tau = 0.50$ and $e = 0.60$. P: proportional allocation; A: equal kilograms; C: capped common ceiling. kt denotes thousand tonnes per year. Positive differences increase the obligation relative to P; negative differences reduce it. Baseline shares use published tonnes. Totals use unrounded calculations, so displayed entries may not sum exactly. These are assigned reductions, not observed effects.

Raising assumed eligibility to 0.70 lowers required delivery to 71.43%; at 80% delivery the target would be exceeded. In contrast, $e = 0.40$ cannot support a 50% target even at full delivery: eligible mass is 8.203 million tonnes short. A different allocation rule cannot remove this constraint on prevention opportunity.

The grid also guards against equating treatment coverage with achievement. A collection programme reaching 80% of households does not necessarily prevent 80% of waste mass. Conversion requires evidence about the affected waste and the share avoided. Once prevention is established, food composition and life-cycle factors are still needed for Equation 9. The table provides checks that should precede that environmental calculation.

Table 10. Aggregate prevention feasibility under target and delivery scenarios

Target (%)	Eligible (%)	Required (Mt)	Eligible (Mt)	Full-delivery slack (Mt)	Required delivery (%)	At 80% delivery (Mt)	Gap at 80% (Mt)
20.00	40.00	16.41	32.81	16.41	50.00	26.25	0.00
20.00	50.00	16.41	41.01	24.61	40.00	32.81	0.00
20.00	60.00	16.41	49.22	32.81	33.33	39.37	0.00
20.00	70.00	16.41	57.42	41.01	28.57	45.94	0.00
20.00	80.00	16.41	65.62	49.22	25.00	52.50	0.00
20.00	90.00	16.41	73.82	57.42	22.22	59.06	0.00
30.00	40.00	24.61	32.81	8.20	75.00	26.25	0.00
30.00	50.00	24.61	41.01	16.41	60.00	32.81	0.00
30.00	60.00	24.61	49.22	24.61	50.00	39.37	0.00
30.00	70.00	24.61	57.42	32.81	42.86	45.94	0.00
30.00	80.00	24.61	65.62	41.01	37.50	52.50	0.00
30.00	90.00	24.61	73.82	49.22	33.33	59.06	0.00
40.00	40.00	32.81	32.81	0.00	100.00	26.25	6.56
40.00	50.00	32.81	41.01	8.20	80.00	32.81	0.00
40.00	60.00	32.81	49.22	16.41	66.67	39.37	0.00
40.00	70.00	32.81	57.42	24.61	57.14	45.94	0.00
40.00	80.00	32.81	65.62	32.81	50.00	52.50	0.00
40.00	90.00	32.81	73.82	41.01	44.44	59.06	0.00
50.00	40.00	41.01	32.81	-8.20	125.00	26.25	14.76
50.00	50.00	41.01	41.01	0.00	100.00	32.81	8.20
50.00	60.00	41.01	49.22	8.20	83.33	39.37	1.64
50.00	70.00	41.01	57.42	16.41	71.43	45.94	0.00
50.00	80.00	41.01	65.62	24.61	62.50	52.50	0.00
50.00	90.00	41.01	73.82	32.81	55.56	59.06	0.00
60.00	40.00	49.22	32.81	-16.41	150.00	26.25	22.97
60.00	50.00	49.22	41.01	-8.20	120.00	32.81	16.41
60.00	60.00	49.22	49.22	0.00	100.00	39.37	9.84
60.00	70.00	49.22	57.42	8.20	85.71	45.94	3.28
60.00	80.00	49.22	65.62	16.41	75.00	52.50	0.00
60.00	90.00	49.22	73.82	24.61	66.67	59.06	0.00
70.00	40.00	57.42	32.81	-24.61	175.00	26.25	31.17
70.00	50.00	57.42	41.01	-16.41	140.00	32.81	24.61
70.00	60.00	57.42	49.22	-8.20	116.67	39.37	18.05
70.00	70.00	57.42	57.42	0.00	100.00	45.94	11.48
70.00	80.00	57.42	65.62	8.20	87.50	52.50	4.92
70.00	90.00	57.42	73.82	16.41	77.78	59.06	0.00

Note: Author calculations using Equation 10, with $T = 82.02722$ million tonnes. Eligibility and effective delivery are scenario assumptions, not measured country prevention shares or participation rates. Full-delivery slack equals $(e-\tau)T$; a negative value indicates infeasibility even at 100% delivery. Required delivery above 100% is infeasible. The gap at 80% is $\max(\tau - 0.80e, 0)T$. No greenhouse-gas factors are applied.

5.3 Measurement Governance and Evaluation Design

The verification bounds show what a chosen measurement tolerance means for a progress claim. Equation 8 gives the measured decline needed for certification. Better comparability narrows η; choosing a different estimate leaves the measurement problem unresolved. The lower bound should not be presented as the likely outcome because the analysis assigns no probabilities to errors.

Sampling and systematic errors require different responses. Sampling error reflects observed households or waste events. Systematic error can arise from omitted disposal routes, changed definitions, or reporting behaviour. A stable multiplicative bias cancels in a ratio, but evidence is needed to confirm its stability. When methods change, parallel collection or a bridge study can test whether the old and new series remain comparable.

A practical audit need not have the same error tolerance in both rounds. A well-documented baseline may be followed by a comparable survey, or follow-up measurement may improve while uncertainty remains in the historical baseline. With bounds η_0 and η_1 for baseline and follow-up, the generalisation of Equations 7–8 is

$$\begin{aligned} R_{\min} &= 1 - (1 - \widehat{R})\frac{1+\eta_0}{1-\eta_1}, \\ R_{\max} &= 1 - (1 - \widehat{R})\frac{1-\eta_0}{1+\eta_1}, \\ \widehat{R}_{\text{required}} &= 1 - (1-\tau)\frac{1-\eta_1}{1+\eta_0}. \end{aligned} \tag{11}$$

Table 11 contains all 36 combinations of the specified tolerances. With a 10% baseline bound and 5% follow-up bound, an observed decline of 50% implies a true reduction of 42.11–57.14%; certification requires a measured decline of 56.82%. Reversing the bounds gives a range of 41.67–56.82% and a certification threshold of 57.14%. The difference arises because baseline error is in the numerator and follow-up error is in the denominator of Equation 6.

Reducing both bounds from 10% to 5% narrows the possi-

ble reduction range from 20.20 to 10.03 percentage points. Improving only the baseline gives a 15.15-point range; improving only follow-up gives 15.04 points. These changes show sensitivity but do not account for audit costs. An authority deciding where to invest in measurement also needs to know how much precision can be improved and at what cost; the most precise survey is not necessarily the best use of resources.

Methodological concerns in measurement and intervention evidence reviewed by Baquero et al. [13] and Casonato et al. [4] imply that evaluations should specify outcomes, comparators, frequency, and reach before implementation. Randomisation or a defensible quasi-experiment can identify programme effects. The accounting model supplies the objective against which those effects can be assessed.

Public reporting should show intensity, total mass, and evidence support together. Their 0.222 rank correlation shows that one metric cannot stand in for the other. Bounded comparisons identify positions sensitive to measurement tolerance. A one-place movement in a league table is not evidence of changed household practice or policy effectiveness.

5.4 Limitations and Research Priorities

The core sample is selected by evidence designation and reporting source and has strong representation from European countries. It is not a sample of nations. Estimates combine study periods and methods, while published labels do not provide numerical standard errors. The analysis therefore draws no conclusions about a global average. An expanded 93-economy sample tests sensitivity to coverage.

The 60% cap is a planning assumption. Countries should replace it with evidence about composition and prevention potential, separating edible food from inedible parts where possible. If all acceptable shares are below 50%, a 50% target is infeasible under the stated constraints. Changing d or c cannot fix the shortfall; prevention opportunities or target scope must change.

Marginal costs, fiscal capacity, and within-country distribution are not included. The calculations focus on physical burden principles rather than welfare maximisation. Cost min-

Table 11. Asymmetric measurement tolerances and progress verification

Baseline bound (%)	Follow-up bound (%)	True minimum (%)	True maximum (%)	Required measured (%)	Width (pp)
0.00	0.00	50.00	50.00	50.00	0.00
0.00	2.50	48.72	51.22	51.25	2.50
0.00	5.00	47.37	52.38	52.50	5.01
0.00	10.00	44.44	54.55	55.00	10.10
0.00	15.00	41.18	56.52	57.50	15.35
0.00	20.00	37.50	58.33	60.00	20.83
2.50	0.00	48.75	51.25	51.22	2.50
2.50	2.50	47.44	52.44	52.44	5.00
2.50	5.00	46.05	53.57	53.66	7.52
2.50	10.00	43.06	55.68	56.10	12.63
2.50	15.00	39.71	57.61	58.54	17.90
2.50	20.00	35.94	59.38	60.98	23.44
5.00	0.00	47.50	52.50	52.38	5.00
5.00	2.50	46.15	53.66	53.57	7.50
5.00	5.00	44.74	54.76	54.76	10.03
5.00	10.00	41.67	56.82	57.14	15.15
5.00	15.00	38.24	58.70	59.52	20.46
5.00	20.00	34.38	60.42	61.90	26.04
10.00	0.00	45.00	55.00	54.55	10.00
10.00	2.50	43.59	56.10	55.68	12.51
10.00	5.00	42.11	57.14	56.82	15.04
10.00	10.00	38.89	59.09	59.09	20.20
10.00	15.00	35.29	60.87	61.36	25.58
10.00	20.00	31.25	62.50	63.64	31.25
15.00	0.00	42.50	57.50	56.52	15.00
15.00	2.50	41.03	58.54	57.61	17.51
15.00	5.00	39.47	59.52	58.70	20.05
15.00	10.00	36.11	61.36	60.87	25.25
15.00	15.00	32.35	63.04	63.04	30.69
15.00	20.00	28.13	64.58	65.22	36.46
20.00	0.00	40.00	60.00	58.33	20.00
20.00	2.50	38.46	60.98	59.38	22.51
20.00	5.00	36.84	61.90	60.42	25.06
20.00	10.00	33.33	63.64	62.50	30.30
20.00	15.00	29.41	65.22	64.58	35.81
20.00	20.00	25.00	66.67	66.67	41.67

Note: Author calculations using Equation 11. True-reduction bounds condition on a measured 50% decline. The required measured decline assures at least a 50% true reduction within the chosen error set. Each row gives a pair of absolute multiplicative bounds, not realised error signs. Width is in percentage points. These deterministic intervals have no probability or confidence-level interpretation.

imisation would require credible marginal prevention costs; effects assessment would require explicit welfare weights. These inputs may be added if comparable evidence becomes available while preserving a common B.

Error tolerances are scenarios, not national error rates. Field studies could support tolerances, shared errors, or probability distributions. The exact bounds provide checks for extensions and make clear which conclusions depend on assumptions about uncertainty.

6. CONCLUSION

This study uses evidence available through March 2025 to connect how household food waste is allocated among countries with the process of verifying progress. The 38-economy core accounts for 82.03 million tonnes. A 50% reduction requires 41.01 million tonnes. With a 60% cap, the same requirement produces uniform 50% obligations under proportional allocation, country reductions of 30.43–60% under equal kilograms, and reductions of 0–60% under capped convergence. The aggregate goal alone does not determine each country's contribution.

Alternative allocation rules reassign 5.61–6.16% of the mass requirement across countries. With assumed eligibility of 60%, a 50% target still requires effective delivery of 83.33%. Asymmetric audit bounds show why improving one measurement round can change the interpretation of an observed reduction.

Priority selection depends on the metric. The five countries with the largest total waste volumes account for 60.99% of core mass, compared with 17.33% for the five highest per-person estimates; Italy is the only country in both lists. Under 10% measurement error, 61.45% of country pairs remain clearly distinguishable. A measured 50% reduction may represent a true reduction from 38.89% to 59.09% when errors differ between rounds.

A practical policy should state its allocation principle, confirm prevention feasibility by ensuring $e \geq \tau$, and maintain consistent measurement boundaries. Composition audits support caps, local evaluations confirm delivery, and repeated measurements support verification. Publishing these choices makes the distribution and physical meaning of a percentage commitment open to examination before performance is judged.

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