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Research Paper

Source-separation infrastructure and the reduction of residual household waste: Evidence from Iceland's 2023 waste reform

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ABSTRACT

This study evaluates whether Iceland's 2023 waste-management reform, which combined Extended Producer Responsibility (EPR) financing with mandatory four-bin kerbside collection, reduced targeted household waste remaining in the general bin. Using a decade-long dataset (2014–2025) derived from systematic waste characterisation studies, the analysis employs a panel Interrupted Time Series (ITS) design comprising 55 observations across five analytical areas in the Capital Region to quantify changes in residual biodegradable waste, paper, plastic, and non-targeted fractions. The results indicate a statistically significant structural break in household disposal behaviour, with total waste in the general bin declining by an average of 37 % following the reform. This shift is primarily driven by a pronounced "organic transition," as biodegradable waste remaining in the residual stream decreased by 54 %. By 2024, total apparent capture rates for paper and plastic reached peaks of 83 % and 44 %, respectively, before showing slight stabilisation in 2025.

These findings suggest that the EPR framework provided an important financial and regulatory foundation, but the decisive behavioural mechanism was the rollout of accessible household-level source-separation infrastructure, especially for biodegradable kitchen waste. For paper and plastic, observed changes are more consistent with the continuation and reinforcement of pre-existing downward trends alongside improved post-reform apparent capture rates. However, the slight stabilisation in performance by 2025 is consistent with a tendency for initial participation gains to diminish over time, highlighting the importance of sustained behavioural engagement, contamination control, and complementary collection pathways for residual materials not targeted by the four-bin system.

1. Introduction

Transitioning to a circular economy is central to modern environmental policy (European Commission, 2020). While its theoretical benefits are well documented, implementing such systems in geographically isolated and demographically sparse nations presents unique challenges (Eisted & Christensen, 2011; Keske et al., 2018). With its sub-Arctic environment, high logistical costs, and reliance on imports, Iceland provides a useful case for examining how circular-economy policy is translated into household waste-management practice under spatial constraints. Historically, the Icelandic waste-management system has lagged behind its Nordic neighbours, characterised by a heavy reliance on landfilling and a fragmented, voluntary approach to recycling (Óskarsson et al., 2022).

The enactment of the Act on the Treatment of Waste (Act No. 55/2003) and the subsequent amendment introduced through the 2021 Waste Management Act (Act No. 103/2021), often referred to as the "Circular Law," marked a decisive shift in national strategy. Fully implemented from January 2023, the reform combined two linked but analytically distinct elements: a harmonised household collection mandate and an Extended Producer Responsibility (EPR) financing framework for packaging waste. In the Icelandic system, the EPR mechanism is primarily financial: producer and importer fees are administered through the Icelandic Recycling Fund and used to support

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the collection and processing of packaging waste, while municipalities remain responsible for organising collection services. The present study evaluates the material-flow effects of this reform on household residual waste composition; it does not estimate cost savings, municipal cost recovery, or the full distribution of costs between producers, municipalities, and households.

In the Icelandic context, the harmonised four-bin system mandates dedicated kerbside collection containers for four household fractions: (1) paper and cardboard, including both packaging and non-packaging printed paper; (2) plastic packaging; (3) biodegradable kitchen waste; and (4) mixed residual waste. This configuration should be understood as Iceland's national implementation of broader EU/EEA separate-collection obligations, rather than as a fixed EU-wide four-bin model. EU waste legislation requires the separate collection of key material streams, but the specific household bin configuration and collection-channel design vary between countries and municipalities. In this article, the terms harmonised and universal therefore refer to standardisation across Icelandic municipalities, not to a uniform European collection model.

Throughout this study, the receptacle for mixed residual waste is referred to as the general bin, roughly equivalent to "trash" or "garbage" in North American terminology. In European waste-policy terminology, residual waste refers to the mixed municipal waste fraction that remains after recyclable and biodegradable materials have been separated through dedicated collection systems. The term infrastructure therefore refers specifically to this household-level bin configuration and its associated kerbside collection services, rather than to downstream recycling plants or transport assets.

Other packaging materials covered by the EPR framework, such as glass bottles and metal cans, are not targeted by the kerbside four-bin system. These materials continue to be managed through neighbourhood drop-off containers and recycling centres. Prior to the 2023 reform, household source-separation arrangements were fragmented: all households had access to a general residual waste bin, but kerbside collection of paper and plastic varied between municipalities, and dedicated kerbside collection of biodegradable kitchen waste was largely absent. Recyclable materials were instead managed through a combination of voluntary municipal kerbside schemes, drop-off containers, and recycling centres. The reform therefore standardised access to household source-separation opportunities across municipalities, while retaining drop-off and recycling-centre channels as complementary infrastructure. Fig. 1 illustrates the shift from the typical pre-reform general-bin configuration to the post-reform household source-separation system, in which the four mandated fractions are commonly implemented through three physical containers. The dual-compartment container contains two physically separated internal chambers with independent collection compartments. Waste cannot move between the chambers during ordinary use; any cross-contamination would therefore result from incorrect household placement rather than mixing within the container.

While prior research has examined the cost and efficiency of Iceland's waste-management reforms (Óskarsson et al., 2022, 2025, 2026), the internal composition of the general bin remains unexplored. Evaluating apparent capture rates alone can be misleading without analysing residual waste composition, especially given confounding factors such as tourism seasonality (Arbulú et al., 2024), gross-weight contamination in separately collected fractions, and diminishing initial participation (Wilson et al., 2025). This study fills this gap through a granular, composition-based longitudinal analysis of Capital Region waste characterisation studies from 2014 to 2025. Focusing on the Capital Region, which encompasses approximately 64 % of the national population, allows the analysis to examine household separation behaviour under relatively stable, high-capacity collection conditions. While this regional focus excludes the most remote municipalities, it provides a robust setting for evaluating household behavioural change because it captures the clear majority of the Icelandic population while reducing confounding effects associated with extreme remoteness, service sparsity, and visitor-generated waste.

By applying Interrupted Time Series (ITS) analysis, we test whether the 2023 reform was associated with a structural break in household disposal behaviour. Because the reform was implemented as a policy bundle, including legal mandates, EPR financing, and household-level collection infrastructure, the ITS estimates should be interpreted as the combined effect of this reform package. The specific mechanism examined, however, is the physical rollout and operationalisation of the harmonised four-bin collection system at the household level. Specifically, we examine whether this infrastructural shift reduced the amount of biodegradable kitchen waste, paper, and plastic remaining in the residual household waste stream. Unlike prior studies that focused on municipal cost efficiency (Dijkgraaf & Gradus, 2015, 2020; Óskarsson et al., 2022, 2025) or aggregate recycling rates (Antonopoulos et al., 2021; Óskarsson et al., 2026), this article provides a granular examination of specific material fractions, offering the first composition-based longitudinal assessment of whether harmonised kerbside source-separation infrastructure can reduce the loss of targeted materials to residual household waste in a high-income island jurisdiction.

Fig. 1. Household waste collection infrastructure before and after Iceland's 2023 waste-management reform. Left: the typical pre-reform configuration, consisting primarily of a single general bin for mixed residual waste. Right: the post-reform four-bin system, which mandates the separation of four household fractions. For single-family and terraced homes, the system is frequently implemented using three physical wheeled bins to optimise space. These comprise a dual-compartment bin with two physically separated interior chambers for biodegradable kitchen waste (green label) and mixed residual waste (black label), a dedicated bin for plastic packaging (purple label), and a dedicated bin for the combined paper-and-cardboard fraction. On the latter bin, the orange label denotes cardboard and paperboard, while the blue label denotes newspapers and other paper. Both categories are placed in the same bin and constitute a single collection fraction. Note: Multi-family dwellings and apartment blocks typically use larger communal containers or other configurations for the same four fractions. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Literature review

The effectiveness of waste management policies is contingent upon a complex interplay of infrastructure, economic incentives, and behavioural norms. This section reviews the theoretical and empirical literature underpinning EPR systems and household separation behaviour, with a specific focus on the unique constraints of remote, island economies.

2.1. Extended producer responsibility and policy instruments

Extended Producer Responsibility (EPR) shifts post-consumer waste management burdens from municipalities to producers, incentivising eco-design and funding collection and recycling systems (Joltreau, 2022; Rodrigues et al., 2016). In practice, however, EPR should be distinguished from the household collection interface. EPR can create the financial and institutional conditions needed to expand services, but producer responsibility alone does not necessarily change household separation behaviour unless residents are given accessible and understandable source-separation opportunities. This distinction is particularly important in the Icelandic case, where the EPR framework finances packaging-waste management but municipalities remain responsible for operating collection services. The reform therefore provides a useful case for examining whether financial regulation translates into behavioural change through improved kerbside convenience. The debate in the literature often centres on the efficacy of economic instruments (e.g., unit-based pricing or "Pay-As-You-Throw") versus physical infrastructure (convenience). Dijkgraaf & Gradus (2015) argue that while unit-based pricing is cost-effective, its environmental impact can be limited if not paired with accessible source-separation options. Conversely, Andersson & Stage (2018) provide compelling evidence from Sweden that the introduction of separate food waste collection infrastructure is a more powerful driver of diversion than weight-based tariffs alone. This supports the "infrastructure-first" hypothesis, suggesting that minimising the physical effort of source separation and reducing the "distance to bin" is a prerequisite for effective pricing mechanisms (Struk, 2017; Xirogiannopoulou et al., 2024).

2.2. The "Organic Revolution" and plastic diversion

A central component of the circular transition is the diversion of biodegradable waste, which poses environmental risk in landfills due to methane emissions. The literature emphasises that organic waste separation is highly sensitive to convenience and system design (Andersson & Stage, 2018). Furthermore, the quality of separated fractions is critical; contamination in plastic streams, for instance, can negate the benefits of recycling (Dijkgraaf & Gradus, 2020). EU-level material flow analyses show that, even in mature source-separation systems, plastic packaging recovery rates remain substantially lower than those of paper, reflecting polymer heterogeneity, sorting losses, and downstream processing constraints rather than a lack of household participation (Antonopoulos et al., 2021). For Iceland, where plastic packaging demand is high but recycling infrastructure has historically been immature (Mager et al., 2022; Ögmundarson et al., 2022), the transition to a mandatory collection system therefore presents both a logistical challenge and a significant opportunity to close the material loop.

However, the persistence of these new separation habits is not guaranteed. Wilson et al. (2025) and Trushna et al. (2024) highlight the role of behavioural interventions and the tendency for participation gains to diminish over time, whereby participation may initially increase following system introduction but subsequently decline as the intervention becomes routine. This phenomenon necessitates longitudinal monitoring rather than static snapshots of performance.

2.3. The context of remoteness and seasonality

Waste management in Iceland operates under structural conditions distinct from those typically observed in continental Europe, despite the country's obligation to implement EU waste legislation through the European Economic Area (EEA) framework. First, the "tyranny of distance" in Arctic and sub-Arctic regions creates diseconomies of scale for waste collection and transport (Eisted & Christensen, 2011; Keske et al., 2018; Sebastian & Louis, 2022). These spatial constraints increase operational costs and complicate the provision of uniform collection services, particularly outside dense urban areas. Second, the intense seasonality of tourism exerts additional pressure on waste infrastructure. Arbulú et al. (2024) and Caponi (2022) demonstrate that tourism flows can distort per-capita waste generation statistics, making it difficult to disentangle resident behaviour from visitor impacts. In Iceland, where tourist arrivals significantly exceed the resident population, analysing waste composition within residential collection routes, rather than relying on aggregate municipal waste statistics, is therefore essential for accurately measuring changes in household disposal behaviour.

3. Methodology

3.1. Data sources and sampling strategy

This study uses systematic waste characterisation data from (SORPA, n.d.), the Capital Region's waste management authority. This region comprises six constituent municipalities (Reykjavík, Kópavogur, Hafnarfjörður, Garðabær, Mosfellsbær, and Seltjarnarnes). It contains approximately 64 % of the national population and represents the largest and most comprehensive municipal waste management system in the country. As such, it provides an appropriate setting for examining structural changes in household waste composition.

The analysis is based on a longitudinal dataset covering the period 2014–2025. Waste characterisation was conducted through repeated manual sampling of residual household waste collected from general bins. During each sampling campaign, individual subsamples of approximately 100 kg were collected and manually sorted into predefined material categories. All manual sorting and weighing were conducted on an "as received" basis (wet weight), reflecting the operational characteristics of municipal solid waste collection systems. No drying or moisture correction procedures were applied prior to weighing. To reduce sampling uncertainty and natural variation in waste generation, annual sampling campaigns consisted of 24–30 independently collected subsamples distributed across municipalities in proportion to population size. The resulting observations were subsequently analysed within a spatial panel framework to improve statistical power and account for variation between analytical areas. During the manual sorting process, materials were classified according to their dominant recoverable material type. Where feasible, minor surface contamination was removed prior to classification. However, items that were heavily contaminated, unrecoverable, or inseparable from adhering contaminants (e.g., heavily grease-soiled paper products) were assigned to the category "Non-targeted Fractions" rather than to recyclable material streams. The original waste characterisation protocol employed by SORPA is substantially more granular than the categories used in the present analysis, classifying waste into more than 30 detailed subfractions that are typically reported within approximately 15 broader material groups. For the purposes of evaluating the behavioural effects of the four-bin collection system, these detailed categories were consolidated into four analytical fractions: biodegradable kitchen waste, paper, plastic, and non-targeted fractions. The "non-targeted fractions" category encompasses all materials not directly targeted by the kerbside paper, plastic, or kitchen biodegradable waste collection systems, including sanitary products, textiles, clothing, non-kitchen organic waste, garden waste, deposit beverage containers, glass, metals, hazardous waste, and miscellaneous residual materials such as vacuum cleaner bags. Although no formal contamination threshold was applied, this protocol reduced the risk of substantially contaminated materials artificially inflating the measured paper and plastic fractions within the residual waste composition analysis.

The number of samples collected annually ranged from 24 to 30, distributed proportionally according to the size of the municipalities, with Reykjavík accounting for approximately half of the samples each year. To minimise the confounding effects of seasonal variation in household waste generation, waste characterisation campaigns were conducted consistently during the autumn months throughout the study period, predominantly in November and occasionally commencing in late October. This temporal consistency enhances the comparability of waste composition observations before and after the 2023 reform. While seasonal effects cannot be entirely excluded, the alignment of sampling periods reduces the likelihood that observed changes are attributable to seasonal fluctuations rather than underlying behavioural or system-level changes. To ensure statistical reliability and maintain a minimum of two samples per observational unit, the region's two smallest municipalities, Mosfellsbær and Seltjarnarnes, were combined into a single analytical unit using a weighted average based on population size and waste quantities. The final dataset, therefore, consists of five analytical areas within the Capital Region: Reykjavík, Kópavogur, Hafnarfjörður, Garðabær, and the combined Mosfellsbær–Seltjarnarnes area. Sampling was temporarily suspended in 2020 due to the COVID-19 pandemic, resulting in a single missing year in the time series.

Once the material composition shares were determined from the sorted samples, these percentages were combined with data from SORPA on the total quantities of residual household waste collected from general bins in each municipality. This allowed the estimation of kg per capita of specific waste fractions in the residual waste stream, calculated separately for each municipality and year.

Within the organic fraction, this study focuses exclusively on kitchen biodegradable waste, excluding other organic fractions such as garden waste, pet waste, and other biodegradable materials. Throughout this article, the terms "biodegradable waste" and "organic waste" are used interchangeably to refer to kitchen food waste, which constitutes the primary target of the separate organic collection system introduced in 2023. This restriction is applied because the new household organic bins are primarily intended for kitchen waste, allowing for a more precise measurement of the specific separation behaviour targeted by the 2023 introduction of separate organic collection.

The introduction of the new four-bin household collection system, including the separate collection of organic waste, was rolled out in the Capital Region between mid-May and mid-September 2023. The waste characterisation sampling for 2023 was conducted subsequently in October and November, capturing the post-implementation environment.

To ensure that annual estimates accurately reflected this mid-year transition, the per-capita waste quantities for 2023 were calculated using a split approach. Waste generated prior to the rollout was estimated using composition percentages from the previous year's characterisation study, while waste generated after the implementation was estimated using the material composition observed in the late-2023 sampling. The annual 2023 estimate, therefore, represents a weighted combination of pre-implementation and post-implementation waste composition, weighted proportionally by the total waste volumes recorded under each regime. While this split estimation provides the most robust quantitative approximation of the transition year, it inherently assumes that household separation behaviour remained static under the old regime. Consequently, this approach does not account for potential anticipatory behavioural shifts, such as increased use of drop-off centres, that may have been driven by pre-rollout public awareness campaigns prior to the physical deployment of the bins.

From 2024 onward, the four-bin system was fully operational across the region, and waste composition estimates are based entirely on post-implementation sampling. Consequently, 2023 represents a transition year in the time series, while the years 2024–2025 reflect the first full years of operation under the new collection system.

To calculate material-specific apparent capture rates, separately collected quantities must be compared with the estimated amounts remaining in the residual waste stream. To achieve this, information on separately collected packaging waste was obtained from (Úrvinnslusjóður, n.d.), the Icelandic Recycling Fund, which reports the total quantities of paper and plastic collected through kerbside collection, drop-off containers, and recycling centres. While drop-off containers and recycling centres primarily serve households, an unquantifiable portion of the paper and plastic collected at these locations inevitably originates from small commercial enterprises utilising public infrastructure. As a result, aggregate collection volumes for these channels may overstate pure household generation. Because pre-2023 historical data from voluntary and fragmented collection channels are not fully comparable to post-reform figures, calculating consistent decade-long longitudinal apparent capture rates is unfeasible. This data limitation underscores the methodological necessity of relying on the material composition of the residual general bin, which has been consistently sampled since 2014, as the most robust and continuous proxy for evaluating shifts in household separation behaviour.

3.2. Longitudinal structure and apparent capture rate calculation

The analysis covers the period from 2014 to 2025, allowing for the examination of medium-term trends before and after the implementation of the 2023 reform. As previously noted, detailed waste characterisation by material fraction is unavailable for 2020; however, total waste quantities in the general bin were recorded, preserving continuity in the aggregate time series. For analytical purposes, the timeline is divided into a pre-reform period (2014–2022) and a post-reform period (2023–2025).

Apparent total capture rates are computed as the ratio of separately collected material to the sum of separately collected material and material remaining in the general bin. Apparent total capture rates were calculated as the quantity collected separately through kerbside collection, drop-off containers, and recycling centres divided by the estimated total material quantity:

$$\text{Apparent total capture rate} = \frac{K + D}{K + D + G} \tag{1}$$

where K represents kerbside collection, D represents collection through drop-off containers and recycling centres, and G represents the estimated quantity remaining in the general bin.

To describe the relative contribution of each collection and disposal channel in Fig. 4, kerbside, drop-off/centre, and general-bin shares were calculated using the same estimated total material quantity as the denominator:

$$\text{Kerbside share} = \frac{K}{K + D + G}, \text{Drop} - \text{off}\Big/\text{centre share} = \frac{D}{K + D + G}, \text{General} - \text{bin share} = \frac{G}{K + D + G} \tag{2}$$

The previously used kerbside apparent capture measure, which excluded drop-off and recycling-centre collection from the denominator, was removed because it could obscure the continuing contribution of these complementary collection channels. These measures provide an operational indicator of the extent to which recyclable materials are diverted from the general bin under the four-bin system.

Because the aggregate weights of separately collected fractions were not manually sorted to isolate moisture and non-targeted contributions (contamination), the metric is referred to throughout this study as an apparent capture rate. This terminology acknowledges that the estimates are derived from gross collected weights and do not adjust for contamination, moisture, or non-target material contributions.

Consequently, the apparent capture rates reported here should be interpreted as operational indicators of diversion performance rather than purity-adjusted material recovery rates. Similar concerns regarding contamination in separately collected packaging streams have been documented by Schuch et al. (2023) and Thoden Van Velzen et al. (2019).

Although the overall time series spans more than a decade, the chronological post-reform period currently includes three annual observations (2023–2025). Standard interrupted time series guidelines typically recommend a minimum of 8 to 12 data points before and after an intervention to reliably estimate regression coefficients (Penfold & Zhang, 2013; Wagner et al., 2002). However, there are no fixed limits regarding the number of data points, as statistical power also depends heavily on the variability within the data and the strength of the intervention's effect (Lopez Bernal et al., 2016). By structuring the data as a spatial panel across five analytical areas, this study yields 40 pre-reform and 15 post-reform observations, effectively surpassing these conventional minimums to provide sufficient statistical power. While the adoption of this spatial panel structure bolsters the overall statistical power of the analysis, the relatively short post-intervention chronological window means that inferential weight remains primarily on immediate level shifts, though pronounced gradual slope changes can still be detected.

3.3. Interrupted time series (ITS) analytical framework

To evaluate whether the 2023 reform is associated with statistically significant changes in residual waste disposal, the study employs a Panel Interrupted Time Series (ITS) design using segmented regression with municipality fixed effects. ITS is a quasi-experimental method widely used in policy evaluation when randomised control designs are infeasible, and when an intervention occurs at a clearly defined point in time (Linden, 2015; Lopez Bernal et al., 2016; Wagner et al., 2002; Wooldridge, 2020).

Transitioning from an aggregate time series to a spatial panel dataset (comprising five geographical areas observed from 2014 to 2025) increases the effective number of observations and improves statistical power. Furthermore, incorporating a panel structure allows the model to explicitly control for unobserved, time-invariant baseline differences between municipalities, such as distinct housing structures or localised socio-demographic factors, that might otherwise confound the results (Wooldridge, 2020).

The segmented panel regression model is specified as:

$$Y_{it} = \beta_0 + \beta_1 T_t + \beta_2 D_t + \beta_3 P_t + \mu_i + \varepsilon_{it} \quad (3)$$

where Y_{it} denotes per-capita residual waste in municipality i in year t; T_t is a continuous time variable capturing the pre-reform baseline trend; D_t is a binary indicator taking the value 0 before 2023 and 1 thereafter, representing the immediate level change (step change) associated with the reform; and P_t is a continuous time-since-intervention variable defined as 0 for all years prior to 2023 and increasing sequentially thereafter (1 for 2023, 2 for 2024, etc.), capturing the change in slope following the reform. The term μ_i represents the municipality fixed effect, and the error term ε_{it} captures unexplained variation (Wooldridge, 2020). Municipality fixed effects control for time-invariant structural characteristics such as housing density, infrastructure configuration, and socio-demographic composition.

Separate Panel ITS models are estimated for total waste in the general bin, kitchen biodegradable waste, paper, plastic, and non-targeted fractions. Estimating models by waste stream allows the analysis to identify heterogeneous behavioural responses to the reform across material categories with differing collection requirements and separation complexities. To maintain consistent model specifications across all waste fractions, the year 2020 was omitted from the regression analyses. The models are therefore estimated as an unbalanced spatial panel. Because panel data frequently violate standard Ordinary Least Squares (OLS) assumptions regarding independent and identically distributed errors, comprehensive diagnostic testing was performed. The Breusch-Pagan test was utilised to assess heteroscedasticity (non-constant variance across municipalities), while the Durbin-Watson statistic was calculated to assess first-order serial autocorrelation (Wooldridge, 2020).

Diagnostic testing indicated the presence of heteroscedasticity in several models. To ensure valid statistical inference and avoid inflated test statistics, all models were therefore estimated using heteroscedasticity and autocorrelation consistent (HAC) standard errors (Wooldridge, 2020). This robust estimation approach adjusts the standard errors and p-values to account for heteroscedasticity and serial autocorrelation in the regression residuals.

All statistical analyses were conducted using the R statistical computing environment (R Foundation for Statistical Computing, n.d.). Standard linear regression functions with factor variables (the Least Squares Dummy Variable approach) were used to estimate the fixed-effects models, while the lmtest and sandwich packages were employed to calculate the robust HAC standard errors.

4. Results and discussion

4.1. Structural changes in residual waste and the organic transition

Table 1 reports the average per-capita amount of waste disposed in the general bin across the five analytical areas before (2014–2022) and after (2023–2025) the implementation of the 2023 reform.

Across all residual fractions, the results show a substantial reduction in material remaining in the general bin following the reform. Total waste in the general bin declined 37 % (144.9 to 91.4 kg/capita/year). Biodegradable waste showed the largest decrease (54 %, 61.8 to 28.4 kg/capita/year), while plastic and paper fell by 42 %, respectively. In contrast, non-targeted fractions declined only marginally (−6 %, 41.6 to 39.1 kg/capita/year).

Fig. 2 illustrates the temporal development of total waste in the general bin from 2014 to 2025, disaggregated into biodegradable waste, paper, plastic, and non-targeted fractions.

Fig. 3 presents the proportional composition of the general bin over the same period.

Prior to the reform, total waste in the general bin remained relatively stable (135–155 kg/capita/year), with biodegradable waste constituting the largest fraction throughout the period. Notably, even during the societal disruptions associated with the COVID-19 pandemic (2020–2021), per-capita residual waste levels showed only modest variation. This temporal stability suggests that the pronounced decline observed from 2023 onward is unlikely to reflect broader macroeconomic or societal shocks alone and is instead consistent with the timing of the 2023 policy reform and the introduction of separate collection infrastructure. Following the reform, total residual waste declined sharply, falling from 135 kg/capita in 2022 to 82 kg/capita in 2024, before stabilising at 88 kg/capita in 2025.

Table 1
Average per-capita waste in the general bin before and after the 2023 reform.

Waste Stream	Pre-Reform Mean (2014–22) (kg/capita/year)	Post-Reform Mean (2023–25) (kg/capita/year)	Average Reduction (%)
Total waste in the general bin	144.9	91.4	−37 %
Biodegradable Waste	61.8	28.4	−54 %
Paper	15.8	9.1	−42 %
Plastic	25.7	14.8	−42 %
Non-targeted Fractions	41.6	39.1	−6 %

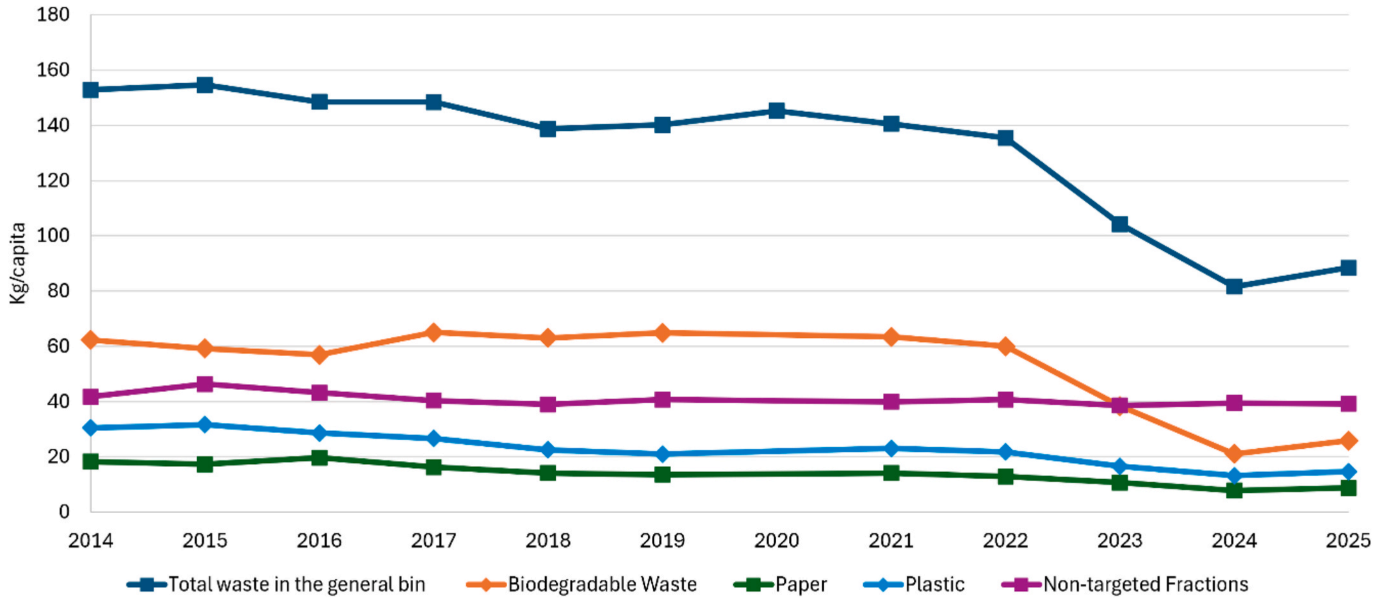

Fig. 2. Total waste in the general bin (kg/capita) and its material composition (biodegradable waste, paper, plastic, and non-targeted fractions).

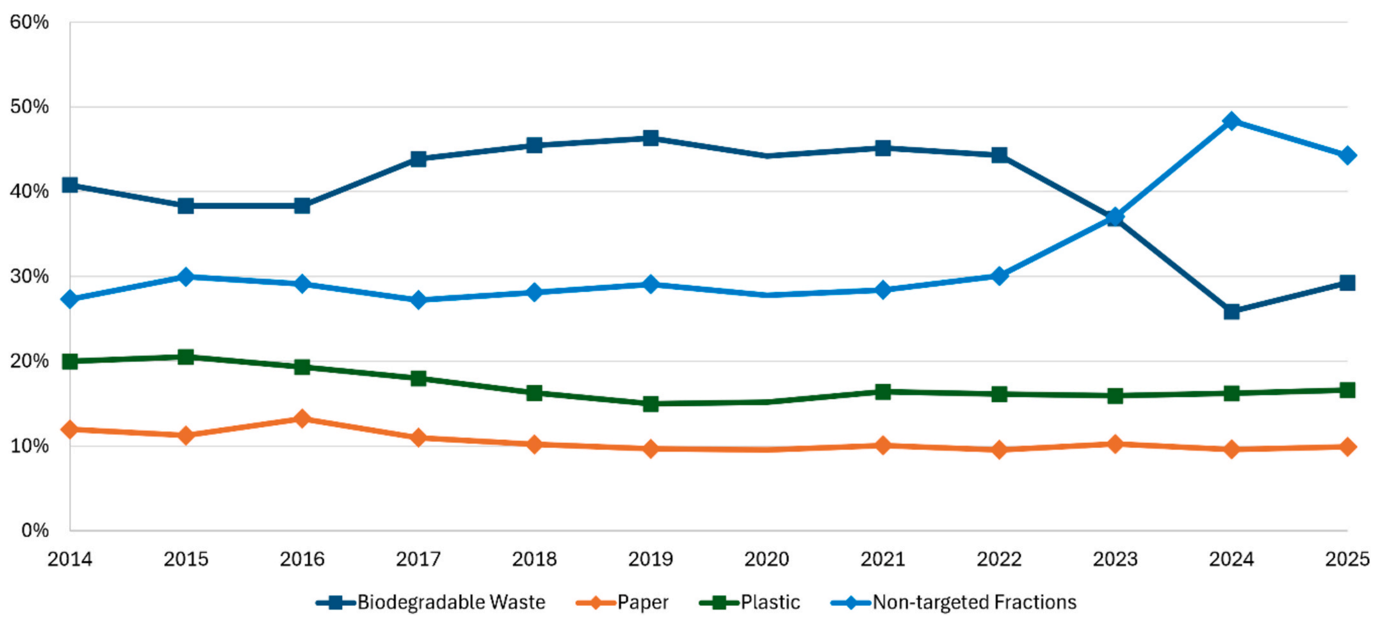

Fig. 3. Proportional composition of the general bin by material fraction.

The reform's impact was highly concentrated; approximately two-thirds of the total waste decline in the general bin is attributed to biodegradable waste alone, highlighting the pivotal role of the new organic waste collection system. The sharp decline following implementation suggests that the introduction of dedicated household organic collection successfully removed a major barrier to diversion, supporting the infrastructure-first hypothesis (Andersson & Stage, 2018; Struk, 2017).

Importantly, the trajectory of non-targeted fractions provides a useful internal comparator. Despite the broad regulatory scope of the 2023 "Circular Law," the aggregate reduction in other waste quantities was comparatively marginal (−6 %). This reflects the fact that these materials are either not fully covered by existing collection schemes or are inherently difficult to divert. As biodegradable waste was diverted, the general bin became increasingly dominated by these heterogeneous residual materials.

4.2. *Segmented regression analysis of reform effects*

Table 2 presents the results of the Panel Interrupted Time Series (ITS) segmented regression models, estimating changes in the amount of waste disposed in the general bin.

The Durbin–Watson statistics are reported as descriptive diagnostics of first-order residual autocorrelation. Because several statistics departed from the benchmark value of approximately 2, and because residual dependence could not be excluded, HAC standard errors were applied consistently across all models. The statistical significance reported for the regression coefficients is based exclusively on the HAC-adjusted coefficient tests.

The ITS results confirm the principal descriptive patterns. For total waste in the general bin, the reform was associated with a highly significant immediate level reduction of 42.66 kg/capita ($p < 0.001$). Biodegradable kitchen waste exhibited the largest reform effect, with an

Table 2
Panel interrupted time series regression results for waste in the general bin (2014–2025).

Variable	Total Waste in General bin	Biodegradable Waste	Paper	Plastic	Non-targeted Fractions
Intercept β_0	162.15***	59.45***	21.09***	35.60***	46.20***
Time Trend β_1	−1.49***	0.56	−0.87***	−1.43***	0.08
Reform Level β_2	−42.66***	−31.31***	−1.59	−4.02*	−4.15*
Post-Slope Change β_3	−6.71	−5.87*	−0.12	0.29	−0.84
R-squared (R^2)	0.95	0.85	0.80	0.63	0.35
D-W statistic	1.362	1.287	2.406	1.629	1.755

Note: Statistical significance of the regression coefficients is based on heteroscedasticity- and autocorrelation-consistent (HAC) standard errors: ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

immediate level reduction of 31.31 kg/capita ($p < 0.001$). The post-reform slope change was also statistically significant (−5.87 kg/capita/year, $p < 0.05$), indicating an additional decline in biodegradable waste remaining in the general bin following implementation.

For paper and plastic, the significant negative pre-reform time trends indicate that the quantities of these materials remaining in the general bin were already declining before the legislative mandate. Plastic exhibited a statistically significant immediate level reduction following the reform ($\beta_2 = -4.02$ kg/capita, $p < 0.05$), but no significant post-reform slope change. Paper showed neither a statistically significant reform-related level change nor a significant post-reform slope change. These results suggest that the four-bin system reinforced and standardised an existing downward trajectory for paper and plastic rather than initiating an entirely new pattern. As discussed in Section 4.1, the pre-existing trends may reflect a combination of expanding voluntary collection, increasing household familiarity with source separation, declining printed-paper consumption, and packaging lightweighting.

Finally, non-targeted fractions exhibited a statistically significant immediate level reduction of 4.15 kg/capita ($p < 0.05$) coinciding with the reform. However, the absence of a significant post-reform slope change indicates that the reform was not associated with a continuing decline in these materials after the initial adjustment.

4.3. *Material-specific apparent capture rates and collection-channel distribution*

Table 3 reports the underlying per-capita quantities of biodegradable waste, paper, and plastic collected through kerbside services and drop-off facilities or remaining in the general bin. These absolute quantities complement the proportional distribution shown in Fig. 4 and allow the relative contribution of each collection channel to be interpreted alongside the magnitude of the material flows.

Table 3
Per-capita quantities of biodegradable waste, paper, and plastic by collection and disposal channel, 2023–2025.

Year	Collection channel	Biodegradable Waste (kg/capita)	Paper (kg/capita)	Plastic (kg/capita)
2023	Kerbside collection	13.9	18.8	5.5
	Drop-off/Centres		15.1	2.7
	Remaining in General Bin	38.4	10.7	16.6
	Estimated total material quantity	**52.3**	**44.6**	**24.8**
2024	Kerbside collection	27.2	24.1	8.6
	Drop-off/Centres		13.4	1.7
	Remaining in General Bin	21.1	7.8	13.2
	Estimated total material quantity	**48.3**	**45.3**	**23.5**
2025	Kerbside collection	29.0	23.2	8.3
	Drop-off/Centres		13.7	1.9
	Remaining in General Bin	25.9	8.8	14.7
	Estimated total material quantity	**54.9**	**45.7**	**24.9**

Notes: Estimated total material quantity is the sum of kerbside collection, drop-off containers and recycling centres, and the estimated quantity remaining in the general bin. Biodegradable kitchen waste was collected exclusively through kerbside collection in the data used for this analysis; therefore, no drop-off quantity is reported. Values may differ slightly from calculated apparent capture percentages because of rounding.

The transition from 2023 to 2024 partly reflects the movement from a partial implementation year to the first full year of operation. For biodegradable waste, kerbside collection increased from 13.9 kg/capita in 2023 to 27.2 kg/capita in 2024, while the amount remaining in the general bin declined from 38.4 to 21.1 kg/capita. In 2025, kerbside collection increased slightly to 29.0 kg/capita, although biodegradable waste remaining in the general bin rose to 25.9 kg/capita.

For paper and plastic, kerbside collection was the largest separate collection channel, but drop-off containers and recycling centres continued to make an important contribution, particularly for paper. In 2025, 23.2 kg/capita of paper was collected through kerbside services and 13.7 kg/capita through drop-off containers and recycling centres. The latter therefore remained a substantial component of the paper collection system rather than a marginal residual channel.

Fig. 4 presents the proportional distribution of each material across kerbside collection, drop-off containers and recycling centres, and the general bin. Combining the two separate-collection channels, total apparent capture rates were 27 %, 56 %, and 53 % for biodegradable waste; 76 %, 83 %, and 81 % for paper; and 33 %, 44 %, and 41 % for plastic in 2023, 2024, and 2025, respectively. The clearest redistribution occurred for biodegradable waste. The share remaining in the general bin declined from 73 % in 2023 to 44 % in 2024, while the kerbside share increased correspondingly from 27 % to 56 %. In 2025, the kerbside share moderated to 53 %, indicating some stabilisation after the initial implementation period.

Paper showed the strongest overall separation performance. The share remaining in the general bin declined from 24 % in 2023 to 17 % in 2024 and remained below one-fifth in 2025. Importantly, this high level of separation resulted from the combined contribution of kerbside and drop-off collection. Drop-off containers and recycling centres accounted for approximately 30–34 % of the estimated paper quantity throughout the period, confirming that these facilities continued to play a substantial complementary role after the introduction of harmonised kerbside collection.

Plastic showed a more limited redistribution. Although the share remaining in the general bin declined from 67 % in 2023 to 56 % in 2024, it increased slightly to 59 % in 2025. Kerbside collection accounted for approximately one-third of the estimated plastic quantity in 2024 and 2025, while drop-off facilities contributed a further 7–8 %. Thus, even after implementation of the four-bin system, most estimated plastic packaging remained in the general bin.

The difference between paper and plastic likely reflects variation in both material characteristics and household separation behaviour. Paper and cardboard are comparatively homogeneous and generally easy for households to recognise. Plastic packaging, by contrast, includes a wider range of sizes, formats, polymers, and household uses. Larger and more conspicuous items, such as bottles and containers, may be separated relatively consistently, whereas small, lightweight,

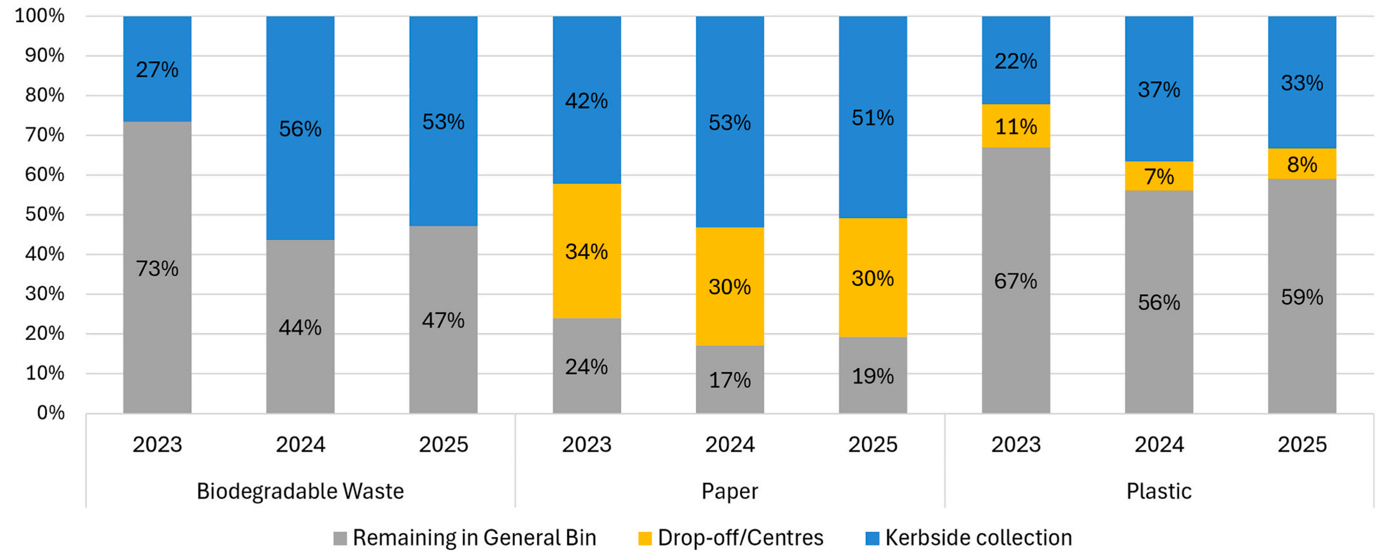

Fig. 4. Distribution of biodegradable waste, paper, and plastic across collection and disposal channels, 2023–2025. Note: Percentages represent each channel's share of the estimated total quantity of the relevant material. Because biodegradable kitchen waste was collected exclusively through kerbside collection in the data used here, no drop-off contribution is shown for this material. Percentages may not sum to exactly 100 % because of rounding.

contaminated, or less salient items, including wrappers and packaging generated in kitchens and bathrooms, are more likely to remain in the general bin. The lower separation of plastic may therefore reflect uneven household participation across packaging types, together with contamination and downstream processing constraints, rather than a general absence of household participation (Antonopoulos et al., 2021; Dijkgraaf & Gradus, 2020; Thoden Van Velzen et al., 2019).

4.4. Behavioural dynamics, stabilisation, and policy implications

Although the reform was associated with an immediate reduction in residual waste, the slight increase in total waste in 2025 suggests an early stabilisation following the initial adjustment period. This pattern is consistent with the possibility that initial participation gains may moderate as a newly introduced collection system becomes embedded in everyday routines (Trushna et al., 2024; Wilson et al., 2025).

The persistence of substantial material remaining in the general bin, particularly non-targeted fractions and remaining recyclable materials, suggests that household-level four-bin infrastructure alone cannot fully eliminate the disposal of targeted materials in residual household waste. This should not be interpreted as evidence that drop-off systems should simply be replaced by kerbside collection. Rather, the results indicate that once convenient kerbside access has been provided for the main targeted fractions, further improvements depend increasingly on complementary measures. These include targeted communication, feedback mechanisms, social-norm reinforcement, contamination control, and continued improvement of complementary drop-off and recycling-centre pathways for materials not directly targeted by the four-bin system (Trushna et al., 2024; Wilson et al., 2025). At the same time, further reductions in the "non-targeted fractions" category are unlikely to be achieved through behavioural reinforcement alone. They may require additional or better-designed collection pathways for materials not targeted by the four-bin system, such as textiles, e-waste, glass, metals, hazardous waste, bulky waste, and non-kitchen organic fractions.

From a broader perspective, the magnitude and speed of the observed reductions substantially revise expectations regarding Iceland's trajectory towards European landfill-reduction targets. Earlier assessments projected slow convergence under a voluntary regime (Óskarsson et al., 2022, 2025); the structural shift identified here demonstrates that harmonised regulation combined with universal infrastructure can compress this timeline considerably, even in a high-income system operating under pronounced logistical constraints. In this sense, the 2023 reform represents not only a compliance mechanism but a credible pathway for accelerating circularity in structurally constrained waste systems.

5. Limitations

Several limitations of this study should be acknowledged. First, the analysis focuses on the Capital Region of Iceland, which benefits from relatively dense settlement patterns and high-capacity waste collection infrastructure. The results may not fully generalise to more remote or sparsely populated regions where logistical constraints are more pronounced.

Second, the study employs a spatial panel Interrupted Time Series design comprising 55 observations across five geographical areas. While this approach increases statistical power and controls for time-invariant differences between municipalities, causal attribution remains complex in the presence of a "policy shock" where legal mandates and infrastructure rollouts occur simultaneously.

Third, although tourism seasonality is a known driver of municipal waste generation in Iceland, the stability of foreign visitor arrivals between 2023 and 2025, which remained nearly static at approximately 2.2 million annually (Hagstofa Íslands, n.d.), suggests that visitor flows are unlikely to have materially distorted the post-reform longitudinal trends. By specifically analysing residential collection routes, this research further minimises the confounding effects of visitor-generated waste compared to aggregate municipal data.

Fourth, waste characterisation data were unavailable for 2020 due to pandemic-related disruptions. While total waste in general bin quantities were recorded for that year, preserving continuity in the overall time series, the absence of material-specific composition data for 2020 introduces minor uncertainty into the precise estimation of long-term compositional trends.

A significant methodological limitation concerns the calculation of apparent capture rates for separately collected fractions, particularly paper and plastic packaging. Because the separately collected streams were not manually characterised, the estimates are derived from gross collected weights and do not adjust for contamination, moisture, or non-target material contributions. As documented in previous research (Schuch et al., 2023; Thoden Van Velzen et al., 2019), contamination levels in separately collected packaging streams can vary substantially across collection systems and jurisdictions. The apparent capture rates reported here should therefore be interpreted as operational indicators of diversion performance rather than purity-adjusted material recovery rates. Importantly, the primary findings of this study are based on the composition analysis of the residual waste stream and the interrupted time series results, which rely on manually sorted waste characterisation data and are therefore substantially less sensitive to these measurement issues.

A related limitation concerns the interpretation of the pre-reform decline in paper and plastic in the general bin. The ITS models identify statistically significant downward trends before 2023, but the available data do not allow these trends to be decomposed into separate drivers such as expanded voluntary recycling access, changing household norms, changes in material consumption, or packaging lightweighting. Consequently, the paper and plastic results should be interpreted as evidence that the reform reinforced an existing trajectory, rather than as a definitive explanation of why that trajectory began.

Finally, although sampling was conducted consistently during the autumn months throughout the study period to maximise temporal comparability, waste composition can exhibit seasonal variation associated with consumption patterns, holidays, and weather conditions. Consequently, some year-to-year variation may reflect residual seasonal influences that are not fully captured by the study design. However, the consistent use of an autumn sampling window reduces the likelihood that the observed post-2023 changes are primarily attributable to seasonal effects.

6. Conclusion

Iceland's 2023 waste-management reform represents a major shift toward a household collection system associated with rapid reductions in waste remaining in the general bin. Using a panel ITS design on a decade-long dataset from the Capital Region, this study finds that the combination of a mandatory four-bin system and harmonised EPR financing coincided with a structural break in household disposal behaviour. Notably, the reform was associated with an immediate and substantial reduction in residual household waste, driven primarily by a more than 50 % decline in biodegradable material remaining in the general bin. This rapid shift suggests that the provision of dedicated collection infrastructure may unlock substantial diversion potential where a major waste fraction previously lacked a separate collection pathway. The finding aligns with evidence from other Nordic contexts, where separate household collection systems have proven more effective at diverting organic waste than economic incentives alone (Andersson & Stage, 2018).

In contrast, the interrupted time-series models indicate that reductions in paper and plastic remaining in the general bin largely represented the continuation and reinforcement of trends already underway before the reform. These trends may reflect a combination of expanding voluntary collection services, increasing household familiarity with source separation, declining use of printed paper, and packaging lightweighting. The reform appears to have standardised and reinforced this existing trajectory rather than initiating an entirely new pattern. This distinction highlights the importance of accounting for both pre-existing behavioural developments and changes in material consumption when evaluating collection-system interventions.

At the same time, the results point to clear limits of infrastructure-led reform. While paper achieved consistently high total apparent capture rates, plastic performance remained substantially lower. The results suggest that separation varies across plastic-packaging formats: larger and more conspicuous items may be separated relatively consistently, whereas small, lightweight, contaminated, or less salient packages are more likely to remain in the general bin. Contamination and downstream processing constraints may further limit recovery (Antonopoulos et al., 2021; Dijkgraaf & Gradus, 2020; Thoden Van Velzen et al., 2019). Moreover, early signs of stabilisation in apparent capture rates suggest that the largest gains may occur during the initial implementation phase, with subsequent improvements becoming increasingly incremental as new separation practices become embedded in everyday routines.

Taken together, these findings suggest that infrastructure remains a necessary but not sufficient condition for advancing circular economy objectives. While universal separate collection can support rapid and substantial improvements in material diversion, particularly for organic waste, achieving further gains may increasingly depend on addressing material-specific recovery constraints, improving recycling system performance, and sustaining long-term household engagement.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work, the author(s) used Grammarly and Gemini/ChatGPT to improve the readability and language of this manuscript. The content in this manuscript is original input from the authors. After using this tool, the author(s) reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Guðmundur Kristján Óskarsson: Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sveinn Agnarsson:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Brynhildur Davíðsdóttir:** Writing – review & editing, Supervision. **Helgi Thor Ingason:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data are available at the given sources.

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