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Citizen Science-Based Waste Diaries: An Exploratory Case Study of Household Waste in Switzerland

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Abstract: Sustainable Development Goal 12 (SDG 12) and national waste reduction goals require frequent waste analyses for monitoring and governance decisions. We developed and tested a citizen science (CS)-based household waste diary for ten consecutive days with 89 volunteer households in Switzerland as a complementary monitoring option to official composition analyses. Discrepancies between the CS-based household diary data and the official composition analyses ranged between 55–65% less reported waste quantities for minerals, compound products, and plastics and 80–90% less for paper, avoidable food waste, and glass. Household waste diaries should be digitalized and prolonged to 21–28 days, and volunteers from different demographic groups are needed to produce stratified, representative results. We conclude that a hybrid CS study design involving waste composition analyses and waste diaries could reduce self-reporting biases while increasing the monitoring frequencies of household waste compositions. CS-based hybrid household waste projects can be a powerful means to complement the measures identified in the 2022 Swiss action plan against food waste and for data reporting for the SDG 12.3 Food Waste Index.

Keywords: citizen science; household waste diaries; food waste monitoring; SDG 12

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1. Introduction

With 148 kg $\times$ cap^{-1} $\times$ yr^{-1}, Switzerland has a very high per capita household waste quantity that is still incinerated [1]. There is an improvement potential for Swiss households to produce less waste or divert certain waste streams to circular systems, especially for textile fibres, plastics, and organic wastes [1]. Parliamentary initiatives for separate plastic collection and recycling systems and the current action plan against food waste [2] aim to accelerate the transition to a circular economy.

Regular monitoring and data collection on waste quantities and compositions, as well as on different treatment routes, is key to designing, implementing, and measuring the effectiveness of any waste management initiative [3]. For example, the UNEP Food Waste Index aims to support countries in transitioning to a common global measurement approach for household food waste that allows for consistent reporting for Sustainable Development Goal (SDG) 12.3 [4]. Data on waste quantities and compositions are commonly collected through objective measurements, such as waste composition analysis or subjective self-assessments based on waste diaries or questionnaires [5]. Swiss household waste quantities and compositions have been monitored since 1992, every ten years by waste composition analysis. The latest household waste audit in 2022 analysed household waste from 33 communities in Switzerland. Swiss household recycling rates are extrapolated from data from separate waste collection providers, which usually apply waste composition analysis or volumetric assessment at community collection points and shops [1,6]. The recycling quantities, however, refer to residential wastes. The available data does not allow for a further distinction of its origin (households or small companies). Assuming that 60% of the recycled waste originates from households [1], around 220 kg × cap^{-1} × yr^{-1} of household waste is recycled.

Waste composition analyses are time- and resource-intensive [7]. Also, the ten-year gap between the Swiss household waste audits does not allow for effective measuring of yearly trends in waste quantities, composition, or recycling rates. Self-assessment methods are less costly and thus allow for shorter intervals [5]. Recent studies concluded that household waste self-assessment is a reliable, low-cost, and scalable tool in waste research that strengthens pro-environmental behaviour and can provide complementary information for evidence-based decision-making [8,9]. Few Swiss researchers or waste agencies have applied self-assessment methods so far, e.g., food waste [10–12].

Citizen science (CS)-based monitoring of household wastes, i.e., engaging public members to assess their wastes voluntarily, is a promising method to generate large datasets for SDG 12 [13,14]. Repeated CS-based monitoring could detect yearly waste generation and recycling trends at the household level. This would provide important insights for waste management decision-makers to foster transformation towards circular systems [15]. Several European CS projects have been initiated to document wastes, predominantly plastic or food wastes, e.g., Marine LitterWatch and Dumb dumpers [16]. Most initiatives are contributory CS projects, i.e., designed by researchers with members of the public who contribute their waste data, either by waste composition analysis or self-assessments. In Switzerland, for example, the Swiss Litter Report engaged 150 citizens to voluntarily collect and categorize litter on Swiss lake and river shores every month for one year [17]. More recently, CS projects towards co-created regional waste management have also started, e.g., in Catalonia, Spain, allowing citizens to actively engage in transforming household waste collection systems [18].

This case study investigated the potential of CS-based household waste diaries in Switzerland. We developed a household waste diary using the same categories as in the Swiss household waste audit protocol. We tested the diaries with 89 volunteer households in Switzerland for ten consecutive days. Results were compared to data from the latest Swiss household waste audits and research studies to discuss the validity of self-assessed data. The peer-reviewed literature was consulted to identify opportunities, challenges, and synergies between the assessments. We use the literature and waste diary results to explore design possibilities for future Swiss CS-based household waste monitoring. Finally, we discuss how CS-based household waste monitoring could complement the current Swiss action plan against food waste [2] and add to progress reporting for the SDG12.3 Food Waste Index [4].

2. Materials and Methods

2.1. Household Waste Monitoring Protocols

The diaries for household waste are based on the Swiss Federal Office of Environment's [1] household waste audit protocols used for waste composition analysis. The protocol contains the same 18 waste categories as the FOEN audit protocol, including the following four organic waste sub-categories: a. garden wastes (unavoidable), b. meat/fish (avoidable), c. other foods (avoidable), and d. kitchen waste (unavoidable) (Table 1). During ten consecutive days, volunteer households sorted their daily household wastes according to the 18 categories and weighed the categorized household waste fractions (in g/per category) with common kitchen scales. Households logged whether their household waste fractions were finally disposed of or recycled. Data were entered in spreadsheet-based self-assessment diaries (electronically or in a print-out). After monitoring, the household waste diaries were sent back to the study coordinators. An online questionnaire was filled out before the household waste monitoring to gather relevant household information, such as household size and age of household members.

Table 1. Household waste categories and items used in this study, adapted from FOEN [1].

Waste Categories	**Definition, Waste Items**
Organic wastes *thereof*	
a. garden waste (unavoidable)	Potted plants with soil, branches, brushwood, leaves, grass, flowers
b. meat/fish (avoidable)	Fresh meat, charcuterie, dried meat, whole fish, seafood, or parts thereof
c. other foods (avoidable)	Fruit, vegetables, bread and other baked goods, uncooked pasta, cheese, butter, yoghurt, curd and other dairy products, eggs, chocolate, drinks, milk (only liquid), other food waste
d. kitchen waste (unavoidable)	Vegetable and fruit scraps, cheese rinds, bones and fish bones
Paper	Newspapers, magazines, books, brochures, catalogues, notebooks, writing and copy paper, paper handkerchiefs, household paper, paper tablecloths, napkins, paper bags, envelopes
Plastics total *thereof*	Bottles: milk, oil, vinegar and syrup, cleaning agents, detergents, plant fertilizers; buckets: empty paint and plaster; waste and shopping bags, foils, yoghurt pots; cassettes: CD, video, and music; packaging: egg, snacks; polystyrene, rubber, bicycle tyres and tubes, credit cards, candles, wax, plexiglass
PET	PET beverage bottles
Compound products	Furniture, on-electronic household appliances, toys, shoes and carpets made of mixed materials, sports equipment, diapers, sanitary towels, adsorbent cotton, tampons, jewellery, tools (hammer, pliers, etc.), folders, photos, sunglasses, mirrors, Teflon pans, cutlery, etc., with plastic handles
Mineral wastes	Cat litter, stones, ceramics, porcelain, dust (incl. Vacuum cleaner bags), ash, hydro pellets
Compound packaging	Milk and fruit packaging (tetra brik), deep-freeze packaging, plastic aluminium composite (e.g., coffee packaging), cigarette packets
Cardboard	Unplasticized packaging, corrugated cardboard, toilet rolls, egg cartons
Glass	Glass bottles with and without deposit, packaging glass, perfume bottles, etc., window glass, vases, glasses, neon tubes, light bulbs, compact fluorescent lamps
Textiles	Clothes, natural and synthetic fibres, rags, stockings, textile tablecloths and napkins, floor rags, cleaning cloths, curtains, string, backpacks, bags
Electrical and electronic devices	Electrical appliances such as household appliances, radios, lamps, watches, flat irons, air dryers, shaving razors, electric toothbrushes; computer parts, electronic toys, cell phones, cables
Ferrous metals	Tinplate cans (with welded seam), lids, screws, nails, cast iron pans, chrome steel pans with plastic handle
Non-ferrous metals	Beverage cans (without welded seam), aluminium foils, tubes, containers, lids, spray cans, cat food cans, brass and copper parts
Organic natural compounds	Natural wood, leather (with buckles and rivets), fur, hair, charcoal, cork
Batteries	All types of batteries
Hazardous waste	Medication, fever meters, full/half-full paint tubs and spray cans, containers with photo developer, used oil, sprays, etc.
Rest < 8 mm	Waste fraction with a grain size of less than 8 mm

2.2. Volunteer Households and Monitoring Period

A total of 89 volunteer households participated in the CS-based household waste monitoring with household sizes of 1–7 members. Waste was collected and weighed from 241 household members, 10 of whom were children from 0–12 years old. Volunteers comprised students and teachers at the University of Applied Sciences and Arts Northwestern Switzerland (37 households) and their relatives and acquaintances (52 households). The monitoring took place between 25 May and 3 June 2021 (n = 26 households), between

27 April and 6 May 2022 (n = 28 households), and between 27 April and 6 May 2023 (n = 35 households).

2.3. Data Analysis

Diary data on waste quantities per category were extrapolated to annual estimates (kg $\times$ cap^{-1} $\times$ yr^{-1}). Relative waste frequencies were calculated as the number of data values > 0 kg $\times$ cap^{-1} $\times$ yr^{-1} divided by the total number of data values. Mean (M) and standard deviation (SD) of the household waste quantities were determined in R (v4.3.2) and compared to Swiss waste audit data. Differences in the mean waste quantities of the three volunteer household cohorts were assessed in R using Welch's T-tests for unequal variances.

2.4. Literature Analysis

The peer-reviewed literature from scholarly literature search engines (i.e., Web of Science and Scopus) was consulted for the narrative of this study. Research studies discussing the advantages and disadvantages of waste monitoring methods and knowledge gaps related to household waste behaviour and monitoring were included in the literature review. A content analysis of the (i) UN Food Waste Index report and its methodology [4] and (ii) approach and measures outlined in the Swiss action plan against food waste [2] was conducted to identify opportunities for CS-based household waste monitoring.

The research steps of this study and the materials and methods used, as well as the outcomes, are summarized in Figure 1.

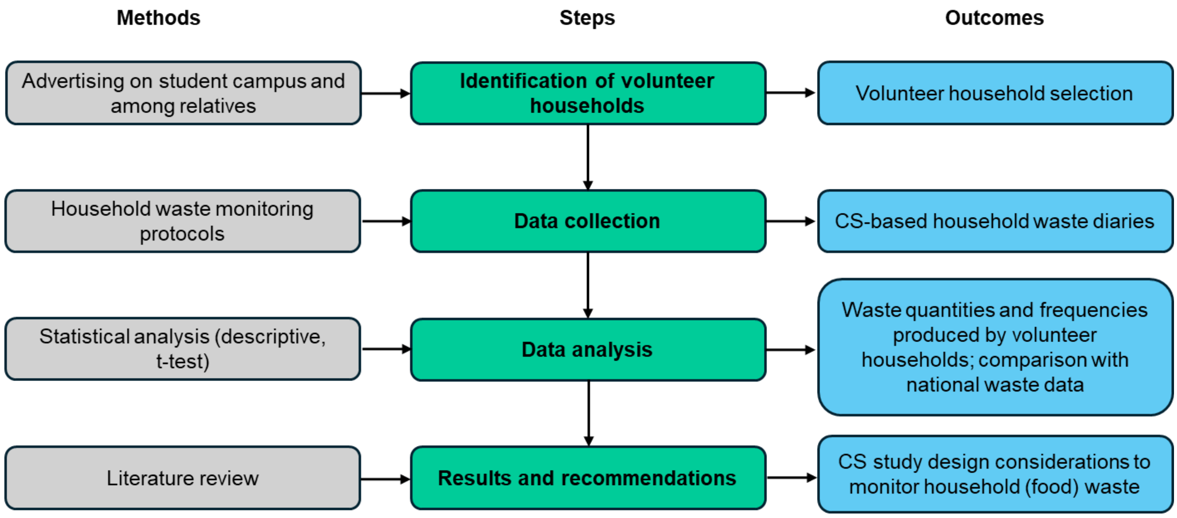


Figure 1. Research flowchart of the exploratory case study.

3. Results

3.1. Comparison of Household Waste Diaries with National Data on Household Wastes

3.1.1. Total Waste Quantities and Quantities Per Waste Category

Over ten consecutive monitoring days, 1130 kg of household waste from the 89 volunteer households was categorized and extrapolated to annual estimates.

The total household waste disposed of and recycled by volunteers (192.5 kg $\times$ cap^{-1} $\times$ yr^{-1}) was only about 52% of the Swiss average of 371.7 kg $\times$ cap^{-1} $\times$ yr^{-1} (Table 1). Volunteer households disposed of 39.5 kg $\times$ cap^{-1} $\times$ yr^{-1}, which is 27% of the 148.2 kg $\times$ cap^{-1} $\times$ yr^{-1} reported in the 2022 Swiss household waste audit [1]. The recycled household waste quantities of the volunteer households were about 68% of the national average figures (223.5 kg $\times$ cap^{-1} $\times$ yr^{-1}, Table 1). Volunteer households recycled 80% of their total household wastes, which is considerably more than the Swiss average with a 51% recycling rate.

The volunteer households monitored the highest waste quantities (disposal and recycling) for organic wastes (81.4 kg × cap^{-1} × yr^{-1}), paper (32.93 kg × cap^{-1} × yr^{-1}), glass (26.63 kg × cap^{-1} × yr^{-1}), compound products (6.95 kg × cap^{-1} × yr^{-1}), cardboard (9.48 kg × cap^{-1} × yr^{-1}), plastics (12.51 kg × cap^{-1} × yr^{-1}), and plastic containers (6.28 kg × cap^{-1} × yr^{-1}). These waste categories also show the highest quantities in the Swiss average household waste data (Table 2). Compared with the latest Swiss waste audit, the volunteer households reported 55–65% less for mineral wastes, compound products, and plastics and 80–90% less for paper, glass, and cardboard. The volunteer households reported 80% less total organic waste and 75–90% less avoidable food waste, i.e., meat/fish and other food waste.

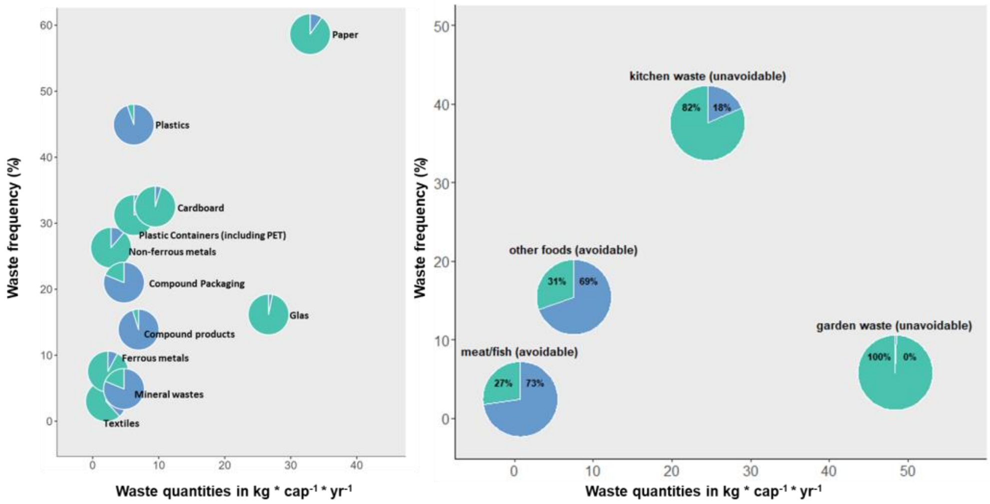
Table 2. Household waste quantities disposed of and recycled in kg cap^{-1} yr^{-1} and % of total household waste quantity. Waste quantities of CS-based waste diaries are presented as mean values (M) and standard deviations (SDs).

Waste Categories	Swiss Waste Audit [1]	Swiss Recycling Quantities (Different Data Sources)	CS-Based Waste Diaries—Disposal	CS-Based Waste Diaries—Recycling
	(kg × cap^{-1} × yr^{-1})	(kg × cap^{-1} × yr^{-1})	(kg × cap^{-1} × yr^{-1})	(kg × cap^{-1} × yr^{-1})
Organic wastes total, *thereof*	52.4 (35.4%)	83.9 [a] (38.0%)	10.46 ± 9.10 (26.5%)	70.6 ± 83.24 (46.3%)
a. garden waste (unavoidable)	*2.1 (1.5%)*	*n.a.*	*0.21 ± 1.08 (<1%)*	*48.2 ± 161.4 (31.6%)*
b. meat/fish (avoidable)	*2.1 (1.5%)*	*n.a.*	*0.51 ± 2.13 (1.3%)*	*0.19 ± 0.99 (<1%)*
c. other foods (avoidable)	*25.2 * (16.9%)*	*27.9 [b**] (12.6%)*	*5.22 ± 14.27 (13.2%)*	*2.3 ± 4.41 (1.5%)*
d. kitchen waste (unavoidable)	*22.9 * (15.5%)*	*27.3 [b] (12.4%)*	*4.52 ± 10.23 (11.4%)*	*19.96 ± 24.73 (13.1%)*
Paper	17.6 (11.9%)	76.1 [a] (34.4%)	3.23 ± 3.33 (8.2%)	29.7 ± 30.26 (19.5%)
Plastics total, *thereof*	19.1 (12.9%)	n.a.	7.01 ± 4.61 (17.7%)	7.85 ± 3.18 (4.8%)
PET	*0.7 (0.5%)*	*2.5 [a] (1.1%)*	*0.09 ± 0.66 (<1%)*	*3.24 ± 4.33 (2.1%)*
Compound products	17.8 (12.0%)	n.a	6.62 ± 23.99 (16.8%)	0.33 ± 1.17 (<1%)
Mineral wastes	8.3 (5.6%)	n.a	3.58 ± 12.09 (9.06%)	0.45 ± 2.46 (<1%)
Compound packaging	8.7 (5.9%)	n.a	3.85 ± 8.33 (9.75%)	0.89 ± 2.81 (<1%)
Cardboard	5.6 (3.8%)	21.5 [a] (9.7%)	0.45 ± 0.89 (1.14%)	9.03 ± 10.32 (5.92%)
Glass	5.5 (3.7%)	24.7 [a] (11.2%)	0.83 ± 4.90 (2.1%)	25.8 ± 22.47 (16.9%)
Textiles	4.1 (2.8%)	3.8 [a] (1.7%)	0.77 ± 2.58 (1.95%)	1.24 ± 8.15 (<1%)
Electrical and electronic devices	0.9 (<1%)	9.1 [a] (4.1%)	0.24 ± 1.47 (<1%)	0.74 ± 5.76 (<1%)
Ferrous metals	1.5 (1.0%)	n.a	0.18 ± 0.91 (<1%)	2.13 ± 9.58 (1.4%)
Non-ferrous metals	2.8 (1.9%)	1.7 [a] (<1%)	0.31 ± 0.61 (<1%)	2.47 ± 2.51 (1.62%)
Organic natural compounds	2.7 (1.8%)	n.a	0.28 ± 1.69 (<1%)	0.19 ± 0.91 (<1%)
Batteries	0.1 (<1%)	0.2 [a] (<1%)	0.0 (0%)	0.2 ± 0.61 (<1%)
Hazardous waste	0.6 (<1%)	n.a	0.06 ± 0.33 (0%)	0.9 ± 7.57 (<1%)
Rest < 8 mm	1.4 (1%)	n.a	1.63 ± 4.14 (4.13%)	0.5 ± 2.61 (<1%)
Total	148.2	223.5	39.52 ± 43.81	152.54 ± 203.03

n.a. = data not available, [a] [6]: Recycling quantities of households presented in the Table are assumed to be 60% of total residential recycling quantities. [b] [19] * kitchen waste (unavoidable) includes vegetable and fruit scraps, meat and fish bones, egg and nut shells and spent coffee grounds; other foods (avoidable) include dairy products, eggs, fruits, and vegetables (cooked and uncooked), bread, rice, pasta, flour, etc., and any other cooked foods and beverage liquids. ** all avoidable food wastes (incl. meat/fish).

3.1.2. Frequency of Disposal and Recycling Per Household Waste Category

Household waste was monitored for ten consecutive days. A similar period was chosen in other household waste self-assessment studies, i.e., seven to fourteen days [5,20]. Not all waste categories were frequently observed within this short sampling period. Waste frequencies show the percentages of positive observations, i.e., waste that occurred over all monitoring observations per waste category. Paper waste, for example, was reported 1044 times from a total of 1780 possible observations during the study period (i.e., a waste frequency of 58.7%). The quantities of paper, plastic, and other unavoidable food waste were observed at >40%. Cardboard and plastic container wastes show a waste frequency of about 30%. The avoidable food wastes, glass, compound packaging, compound products, ferrous metals, mineral wastes, and textiles all show waste frequencies around or below 20% (Figure 2).



(**a**) (**b**)

Figure 2. Quantities of waste and waste frequencies showing the amount of disposal (blue) and amount of recycling (green) in (**a**) each waste category and (**b**) each subcategory of organic waste.

3.1.3. Differences in Waste Quantities of Volunteer Household Cohorts

In 2021, the volunteer households generated the highest total waste quantities (M = 306.0 kg $\times$ cap^{-1} $\times$ yr^{-1}; SD = 278.4 kg $\times$ cap^{-1} $\times$ yr^{-1}). In 2022 and 2023, the total household waste quantities extrapolated were M = 168.9 kg $\times$ cap^{-1} $\times$ yr^{-1} (SD = 219.8 kg $\times$ cap^{-1} $\times$ yr^{-1}) and M = 125.9 kg $\times$ cap^{-1} $\times$ yr^{-1} (SD = 90.4 kg $\times$ cap^{-1} $\times$ yr^{-1}), respectively. The volunteer households in 2021 reported significantly more household waste than the volunteer households in 2023 (t(29) = 3.18, $p < 0.05$) but not than the volunteer households in 2022, (t(34) = 0.97, $p > 0.05$). No significant differences were observed in the total waste quantities reported by the volunteer households in 2022 and 2023 (t(48) = 2.0, $p > 0.05$).

Similar results were obtained for total waste recycling quantities, indicating significant differences only between 2021 and 2023 volunteer household data (t(27) = 2.96, $p < 0.05$). No significant differences were found in total waste disposal quantities among the volunteer household cohorts 2021, 2022, and 2023.

Also, the individual waste category quantities did not differ significantly among the cohorts for disposal or recycling. One exception is the recycled unavoidable kitchen waste and garden waste, which showed a significant difference between 2021 and 2023 volunteer households, t(32)= 2.69, $p < 0.05$ and t(25) = 2.1, $p < 0.05$.

4. Discussion

4.1. Data Comparability, Study Limitations, and General Design Considerations

The diary data can be compared but not correlated with the national data on household waste, as different households were investigated. Results indicate that volunteer households produce half the amount of waste compared with data from the Swiss waste audit. However, the standard deviations of the waste quantities are high, indicating widely scattered data. Future study designs need to improve the selection of volunteer households and increase the number of participating households.

In this study, volunteer selection was not well-balanced to reflect the Swiss average population. All volunteer households showed high pro-environmental behaviour. More than 90% declared to recycle all or almost all recyclable wastes. Representatives of different demographic groups should be included to ensure a more balanced sample of citizens/volunteer households in follow-up studies. The method, however, also seems promising for monitoring the waste and recycling behaviours of groups with similar characteristics. Our study results suggest only a few different behaviours from the three volunteer household cohorts, all consisting of students and their relatives. The significant differences between the 2021 and 2023 cohorts in the total amounts of waste can be partly explained by the sampling period being closer to the gardening season in 2021. Study periods should be carefully selected to consider seasonal effects. Volunteer households should be further characterized to understand additional relevant characteristics, such as age profiles, socio-economic status, or whether a garden is owned or recycling stations are nearby, which can influence their waste and recycling behaviour. An additional stratification into "waste producer profiles" could also result in representative mean values and smaller standard deviations.

The monitoring period of 10 days seems adequate for wastes with a middle to high daily waste frequency of >30–40%. A prolonged reporting period of up to 21–28 days [10,21] should be considered for frequencies below 20%. A prolonged reporting period should also be explored to investigate whether the scattering of the waste data is minimized (Table 1). Electronic waste diaries, e.g., via smartphone apps, should be developed to capture waste that is disposed of or recycled on-route (not via household waste disposal).

Self-assessment data are prone to selection and reporting biases [7]. Reporting biases can occur because of social desirability beliefs (volunteers are prone to report on what is believed to be the socially desirable behaviour) or self-serving tendencies (volunteers deny responsibility for negative environmental behaviours) [20]. Discrepancies between self-assessed and objective measured waste quantities were found in studies by [11,22], reporting 40–90% lower waste quantities with self-assessment methods. Recent findings from household waste research suggest that self-assessment methods underestimate waste quantities and only weakly correlate with measured wastes [23]. Yet, self-assessed diary data allow for recording household waste at the point where it enters waste disposal routes, making identifying and monitoring waste components easier than waste composition analysis (because of waste compaction). With the self-assessment method, other household waste disposal routes, such as recycling and home composting, and psychological factors for waste production can be investigated [10]. Combining self-assessments with waste composition analysis studies in a hybrid approach would merit the strengths of both assessment methods [11,23]. Hybrid study designs would (i) evaluate the validity of self-assessed household waste data, (ii) identify differences in volunteers' perceptions and behaviours, and (iii) allow for the development of producer-specific pro-environmental behaviour change strategies.

4.2. Contributions of Citizen Science-Based Household Waste Monitoring

Most of the household waste occurring in households is avoidable, reducible, or recyclable [1]. Reducing avoidable food waste is the key target of current Swiss waste interventions, i.e., the Swiss Action Plan against Food Waste 2030. Food loss and waste are a priority (reflected in SDG 12.3) because of the related monetary losses, environmental impacts, and the potential to enhance food security [4]. Households are responsible for over 46% of all avoidable food waste generated in Switzerland [24]. Three significant research gaps related to household food waste in Switzerland prevail as follows:

(1) Shortcomings in the methods to quantify and characterize household food waste: The UNEP Food Waste Index (SDG 12.3.1b) aims to support countries in transitioning to a common global measurement approach that allows for consistent reporting under SDG 12.3. The UNEP Waste Index Report 2021 assigns Switzerland low confidence levels for their data gathering methods on household food waste quantification and characterization [4], based on a single study in 2013. The most recent study [19] used Swiss waste composition analysis data [1,25] and secondary data from English and Austrian households to estimate Swiss food waste quantities disposed of via the sink,

home composting, or animal feeding. This increases the confidence levels of the data. The time gap between the Swiss household waste audits remains a drawback for effective progress monitoring for SDG12.3.

(2) Poor understanding of drivers for/against household food waste: The drivers for household waste are complex. The psychological predictors of food waste are being investigated increasingly [10,12,26]. Among the drivers for avoidable household food waste are a general lack of awareness of one's own food waste and of the value of food and insufficient knowledge of food's shelf-life, best practices for storage, and use of leftovers [1,10].

(3) Lack of effective and inclusive interventions to reduce food waste: Research communities are more focused on generating knowledge about drivers behind food waste rather than finding effective interventions [26,27]. A recent review of 17 interventions for consumer food waste prevention [28] concluded that changing the size/type of plates in hospitality environments and changing nutritional guidelines in schools and information campaigns had some quantifiable effects. No robust evidence of effectiveness was found for cooking classes, fridge cameras, food-sharing apps, advertising, or information sharing [28]. Intervention studies that include longitudinal and larger sample sizes are needed to support evidence-based and household-tailored decisions for food waste reduction. The value of co-creative intervention designs, where volunteers are integrated into the process of developing and implementing measures, has been emphasized [29,30] to address the above knowledge gaps, raise awareness of the food waste topic, and improve commitment and responsibility for mitigation among volunteers.

4.2.1. Potential Contributions of CS to the Swiss National Action Plan against Food Waste and Progress Reporting for the Food Waste Index (12.3.b)

The Swiss Government has recently launched its National Action Plan against Food Waste [2]. Food waste includes food loss in agriculture, food processing, and distribution and food waste occurring in retail trade, catering, and households. The action plan pursues three objectives to (i) halve the amount of avoidable food waste by 2030 compared with 2017 as targeted in SDG12.3, (ii) define sector-specific reduction targets together with the sectors, and (iii) reduce the environmental impact of avoidable food waste as much as possible by designing and prioritizing measures accordingly. The action plan will be implemented in Phase I from 2022 to 2025 and Phase II from 2026 to 2030. In Phase I, 14 voluntary mitigation measures will address actors in the food value chain (predominantly the processing industry, retail, and catering). In 2025, the Swiss government will publish up-to-date data on food waste in all stages of the food value chain and assess whether the foreseen mitigation measures are sufficient. If not, the government will take further measures and set more stringent targets for Phase II.

Mitigation measures of Phase I include (i) business initiatives and innovations, such as improving the declaration of shelf-life on end products or optimizing packaging, pack sizes, and sales forms and (ii) public sector measures, such as improving the infrastructure for food donations or providing funding for pilot projects to prevent food waste along the entire value chain. Information and education measures will further target households and the private sector to ensure the dissemination of knowledge about actions to mitigate food waste [2]. Competencies for food waste prevention will be strengthened in vocational education and training, schools, and universities. Producer-specific data collection methods, reduction targets, and indicators for progress reporting will be defined. Two monitoring indicators are proposed as follows:

(1) The quantity indicator shows the amount of avoidable food waste occurring per person and year ($kg_{Foodwaste} \times cap^{-1} \times yr^{-1}$);

(2) The environmental indicator shows the environmental impact of avoidable food waste, expressed in environmental impact points (UBPs) per person and year ($UBP \times cap^{-1} \times yr^{-1}$).

Both indicators are calculated per stage of the food chain (i.e., agriculture, food processing and distribution, retail, catering, and households).

With the quantity indicator and the producer-specific data collection methods, Switzerland could provide accurate and useful data for the SDG 12.3 indicators' Food Loss/Food Waste Index. The Swiss approach would provide level 2 data, i.e., a direct measurement of food waste that is sufficiently accurate for tracking [4]. However, it will be crucial that suitable methods to measure food waste are selected and studies conducted regularly using a consistent methodology. It is unclear in the National Action Plan how this will be performed at the household level (Table 3). The Food Waste Index (SDG 12.3.b) recommends waste composition analysis for waste streams in which food is mixed with non-food and diaries for material that is disposed of in sewer, home-composted, or fed to animals (UNEP, 2021) to provide consistent data for tracking. Diaries even provide level 3 data for SDG 12.3.b. progress reporting since they generate disaggregated data by (i) edible/inedible parts, (ii) alternative disposal destinations, or (iii) gender and socio-economic status. Thus, the proposed indicators in the Swiss Action Plan should be monitored in a hybrid approach (waste composition analysis + diaries). Therefore, level 2 and 3 data for SDG12.3 could be provided.

Table 3. Knowledge gaps related to household food waste and description of measures foreseen to tackle these gaps in the Swiss National Action Plan against Food Waste 2022 and the SDG12.3.b. Food Waste Index.

Knowledge Gaps	**Swiss Action Plan against Food Waste 2022**	**SDG12.3.b—Food Waste Index**
(1) Shortcomings in methods to accurately characterize and quantify household waste over time.	Two monitoring indicators are proposed (amount of avoidable food waste occurring per person and year and environmental impact points per person and year). Unclear how data are collected from households for the two monitoring indicators in the Swiss Action Plan apart from 10-year Swiss household waste audits.	For households, waste composition analysis and waste diaries are recommended to provide a direct measurement of food waste that is sufficiently accurate for tracking (level 2 data).
(2) Poor understanding of drivers for/against household waste.	Not addressed.	Collecting level 3 data is suggested to provide additional information and disaggregation (e.g., by cultural interpretation of edible/inedible parts).
(3) Lack of effective and inclusive interventions to reduce household waste.	Household food waste is addressed with indirect measures in Phase I as follows: (i) Via information campaigns and (ii) Via measures in producer/retail businesses (e.g., setting new expiry dates of products, new package sizes).	Collecting level 3 data is suggested to support the development of food waste prevention strategies (e.g., the disaggregated data by edible and inedible parts is valuable to guide policy interventions).

4.2.2. Design Considerations for a CS-Based Hybrid Household Waste Monitoring Study

Regular CS-based hybrid household waste monitoring, using waste composition analysis and waste diaries, can provide high-confidence level 2 and level 3 data and have immense potential to complement the current Swiss strategies in the Swiss Action Plan against food waste (Table 3).

The involvement of citizen scientists (volunteers) in CS projects can have different forms and imply different levels of engagement. For example, in contributory projects, citizens are only involved in collecting data. Volunteers could thus contribute data on their (food) waste to generate a large dataset that allows them to monitor trends over time (level 3 data). Volunteer households could be further included in waste composition analysis to guarantee a hybrid approach less prone to reporting bias. In collaborative CS, some volunteers are involved in additional stages of the scientific process, e.g., data analysis and dissemination of results. Co-created CS projects try to involve citizens and scientists in all stages, from the setting of the research questions to project design and implementation [31]. All typologies can generate large volumes of household waste data with high spatial and temporal resolution. Collaboration and co-creation profit from the invaluable insights of people closely related to the issue (such as household waste), allowing studies and data collection that would probably be excluded in official/traditional datasets, thus revealing a more comprehensive picture [14]. Collaborative and co-created CS can identify priorities, facilitate learning, prompt innovative solutions and behaviour change, and address social and political aspects of household waste [32].

CS projects often rely on digital technologies and social media to recruit, retain, and train volunteers, collect data, and monitor and adjust interventions. Recent advances in digital information and communication technologies have enabled much broader participation in CS. Smartphones, in particular [33], offer several advantages, including photographs and video cameras, microphones, and access to geographical information. As owners carry these devices around almost constantly, they can easily record observations or use dedicated applications, some designed specifically for CS projects. Similarly, information sharing through social media outlets provides an infrastructure with multiple uses, including harnessing data contributed by the user and using it as a powerful tool to reach diverse audiences and engage them in CS projects.

5. Conclusions

This case study developed and tested household waste diaries with 89 voluntary households in Switzerland to explore how self-assessment methods can complement existing national waste composition analyses and contribute to national and international progress reporting for SDG12. This study concludes that a hybrid CS study design involving waste composition analyses and diaries could increase the validity of self-assessed data by reducing reporting bias while increasing the monitoring frequencies by complementing the time- and resource-intensive waste composition analysis. Representatives of different demographic groups are needed to produce comparable data for all household waste categories. Self-assessment methods should be digitalized and applied for a minimum of 21–28 consecutive days per year for adequate spatio-temporal quantification and characterization of household waste. A CS study is particularly promising in supporting the food waste reduction goals set in the 2022 Swiss action plan against food waste and SDG12.3. This study found the value of CS in being more than just a data-gathering tool but also a method of bringing about change through understanding and influencing interventions towards more circular systems using digital technology and social media. CS-based household waste monitoring can complement the measures identified in Phase I of the 2022 Swiss action plan against food waste. Co-created projects are especially powerful means to provide profound action knowledge for household waste reduction. A CS-based household (food) waste pilot study should test a hybrid waste monitoring approach (waste composition analysis and waste diaries) with volunteers on a smaller regional scale to obtain first-hand feedback on the hybrid process while evaluating the validity of the resulting household waste data. This allows for the development of a robust CS household waste monitoring process with proper data management and quality control, as for level 2 and 3 data reporting for SDG 12.3, and ultimately serves evidence-based governance decisions.

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