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Testing Food Waste Reduction Targets: Integrating Transition Scenarios with Macro-Valuation in an Urban Living Lab

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Abstract: Bristol, one of the United Kingdom's (UK) nine Core Cities, is seeking to achieve Zero Waste City status by 2049. This study combines macro-economic valuation with transition pathway mapping and adapted participatory scenario planning to stress test the city's ambitious food waste targets. The primary aim is to enable better understanding of who might be affected by achieving these targets, both locally and nationally, the potential scale of impacts, and therefore the potential barriers and policy opportunities. The valuation focuses on household and commercial food waste, combining available site and city data with national level proxies. Impact areas include changes in sectoral income, employee income, capital owner income, tax revenue, and carbon emissions. Four scenarios, based on two extreme cases, are modelled to consider food waste reduction and potential shifts in consumption patterns. Results indicate that current market and governance failures incentivise waste, and suggest potential routes to transition, including trade-offs and resource reallocation, alongside the need to acknowledge and respond to these profound structural barriers. With further development and testing, the approach may contribute to a better understanding of how to achieve city socioenvironmental targets.

Keywords: food waste; urban governance; societal impact; urban health; transition pathways; barrier identification; participatory scenario planning; valuation; macro-economics; systems thinking

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1. Introduction

Bristol City Council has ambitious targets to become a "Zero Waste City" by 2049 [1]. This ambition is just one of many in its One City Plan, which it has developed after decades of commitment from Bristol people and notably the work of some flagship charities, institutions, and businesses working in a range of areas, including organic food, ethical banking, healthy transport, and waste reduction. More recently, this plan builds on its European Green Capital 2015 status [2], and the Council's acknowledgement and declaration of both the climate and ecological emergencies [3,4]. Alongside those global concerns about our habitat and health, the dominant political priority under the current Labour Mayor is on addressing inequality [5]. Bristol City plans have also been reassessed recently to monitor them in line with the UN Sustainable Development Goals, including SDGs 3 "Good Health and Wellbeing" and 11 "Sustainable Cities and Communities".

Cities are responsible for 70–75% of global CO_2 emissions and 60% of total global domestic material consumption [6–9]. Urban environments have long been associated with infectious disease, and more recently, with non-communicable diseases (cancers, diabetes, respiratory illness, mental ill-health), which have clear and profound effects on quality of life [10–12]. There is also considerable evidence of the links between urban inequality and health outcomes [13], with food environments a major contributor to both disease and environmental degradation: e.g., access to healthy food and poor nutrition—"food deserts"; cost and quality of food; intensive farming; quantity of food waste; low rates of recycling [14–19]. In the UK alone, an estimated 10 million tonnes of food and drink are wasted post-farm gate annually, worth around £20 billion [20]. In addition, the use of petrochemical products is pervasive and omnipresent across all sectors, not least in food, food packaging, and digestate, contributing to macro and micro-plastics being found in the far corners of the world in the land, sea, and air, with evidence of plastics even in our lungs and the placentas of pregnant women [21,22].

These global challenges have been known about for decades, but in recent years there has been a growing sense of urgency in the research community, with the need for research that contributes more clearly to societal impact being underlined in funding calls and research assessment [23,24]. The "Zero Waste" challenge emerged at the turn of the century and is defined by the Zero Waste International Alliance (ZWIA) as the "*The conservation of all resources by means of responsible production, consumption, reuse and, recovery of all products, packaging, and materials, without burning them and without discharges to land, water, or air that threaten the environment or human health*" [25]. Thinking and development in this area has led to the emergence of the "Circular Economy", which is a "*systematic approach to economic development designed to benefit business, society and the environment*" and is "*regenerative by design and aims to gradually decouple growth from consumption of finite resources*" [26].

In addition to these societal challenges, there are the challenges to the research community of how effective research in this area (i.e., research that leads to societal impact) might be designed and delivered [27,28]. It is now widely accepted that research on complex real world problems such as these must at least involve stakeholders and "end users", if not having them as a core part of the research design and evaluation process from beginning to end [29,30]. This has led to the growing requirement in funding calls for research proposals that are interdisciplinary and transdisciplinary, grounded in co-production [31,32]. One mechanism that was encouraged in the SUGI call was for the use of Urban Living Labs (ULL), which have a wide range of conceptualisations, but are given four key characteristics by JPI Urban Europe: (i) inclusive and profound stakeholder engagement; (ii) responds to challenges and builds capacity; (iii) flexible innovation method open for feedback and learning; (iv) in the midst of everyday urban life [24,33].

This paper was developed following a three-year international research project, WASTE FEW ULL—a Food–Energy–Water (FEW) ULL—which aimed to identify and reduce inefficiencies in the urban FEW "Nexus"—i.e., the interrelationship between these three core resource flows across four ULLs in Bristol (UK), Sao Paolo (Brazil), Western Cape (South Africa), and Rotterdam (the Netherlands). The consortium was funded by the Sustainable Urbanisation Global Initiative (SUGI), a global network of funders convened jointly by JPI Urban Europe and the Belmont Forum [7]. Its focus was on challenges "*connected with population increase and food shortages, scarce water and insufficient energy resources demand solutions*" in order "*to increase the access and the quality of life*". It had a specific goal of sustainable consumption [24] and resides firmly within conceptual challenge areas of Ecological Public Health, One Health, or Planetary Health. Details of the consortium and the Bristol ULL are provided in the Supplementary Material and can be accessed via the website and linked publications [24,34,35].

A core focus for the consortium, especially in Bristol, was the development and testing of non-conventional economic valuations that took into account impacts on community health and wellbeing. This paper sets out macro-valuations, both positive and negative, that may result from achieving Bristol's food waste reduction targets, specifically impacts on: (a) sectoral income and (b) climate (CO_2). It draws on a separate but linked socioenvironmental micro-valuation of food waste, modelling both increased recycling and reduced consumption (GHGs, air pollution, eutrophication) [35]. The macro-valuation focuses on market and benefits across the whole economy via sectoral interactions, while the micro-valuation focuses on non-market costs and benefits in the food waste sector and assumes the rest of the economy was not affected.

The primary innovation of this paper is not the macro-valuation per se. Rather, it is the integration of these two different valuation approaches with the transdisciplinary design process. Made possible via the action research inherent to the urban living lab approach, we integrated these valuation approaches within a transition pathways framework and participatory scenario planning to identify and start to address a complex real world challenge [27,36–38]. The aim was to seek out some initial insight into potential barriers and opportunities in order to: (a) help achieve the city's targets; and (b) sense check whether this approach may be useful and worth developing further (i.e., worth further time/resource for development). The research questions we aimed to answer were:

- What are the consequences to different sectors and the city's climate targets, both intended and unintended, of achieving the One City Plan targets?
- Who are the likely winners and losers (and barriers to change)?
- Might we acquire a sense of the scale of those impacts?
- What are the carbon implications of these changes, and how are wider socioenvironmental implications robustly accounted for?
- What does this mean for policy, both locally at the city level, and nationally?
- Is this valuation approach useful and robust? What more is needed?

We start by setting out the process of problem identification, the data on household and commercial food waste, and how we determined collectively the scenarios to use (Section 2). We then describe the results (Section 3), followed by discussion in relation to the research questions raised above (Section 4).

2. Materials and Methods

Figure 1 illustrates the integration of the multiple methods employed through the urban living lab over the project period, with clear demarcation between "problem space" and "solution space".

2.1. Problem Identification through Participatory Action Research

Problem identification in Bristol started with fuzzy boundaries [39], given, as stated above, that a core premise of both the funding call and the research proposal was the need for co-production with ULL partners. The group started by holistically considering the city's food, energy, and water systems [24], with considerable discussion and iteration defining and redefining boundaries of each system based on stakeholder perception of priority areas and data availability.

The focus ultimately narrowed to the city's waste treatment plant, located to the west of the city on the flat lands at the mouth of the River Avon, which flows through Bristol to the Bristol Channel. More specifically, the focus went to the flows of water and nutrients (food waste and sewage) through the site, and the energy being used in those processes. The site is owned by Wessex Water, and managed by its subsidiary, GENeco, which develops sustainable solutions with waste products (biomethane, biofertiliser, food waste, liquid waste, compost) [40]. The site comprises a wastewater treatment works, anaerobic digestor, and ancillary biogas and composting facilities. It processes almost all the residential food waste from across the city, which is collected by Bristol Waste, the Council-owned waste processing company, as well as around half the commercial food waste [41]. Supporting these companies was Resource Futures, a Bristol-based B-Corp environmental consultancy [42]. In addition to experienced representatives from these organisations were leading experts in food and energy from The Bristol Food Network and

Centre for Sustainable Energy [43,44]. The main issues for Bristol's FEW Nexus that were raised by these practitioners during the initial phase of action research were:

1. The amount of unnecessary food waste (i.e., the need to reduce "avoidable" food waste);
2. The need to improve rates of recycling (i.e., minimising the food waste that goes into the "residual" waste bins);
3. Deteriorating soil quality (locally, nationally, and internationally) and lack of quality compost (which links to the nutrients in sewage, environmental impacts from overuse and geopolitical concerns regarding long-term phosphorous supply) [45];
4. Waste of precious resources, whether finite, made unavailable, or transferred to the "wrong place" (i.e., energy used unnecessarily and carbon emissions from the production and transport of wasted food; unhealthy concentrations of resources leading to pollution; resources flowing in to the sea where they cannot be recaptured; resources bound chemically to improve water quality unavailable for food growing; resources contaminated with plastics being unusable) [46];
5. Plastic in the food waste (e.g., wet wipes and other plastics in sewage; food caddy liners, though biodegradable, being harder to remove from food waste).

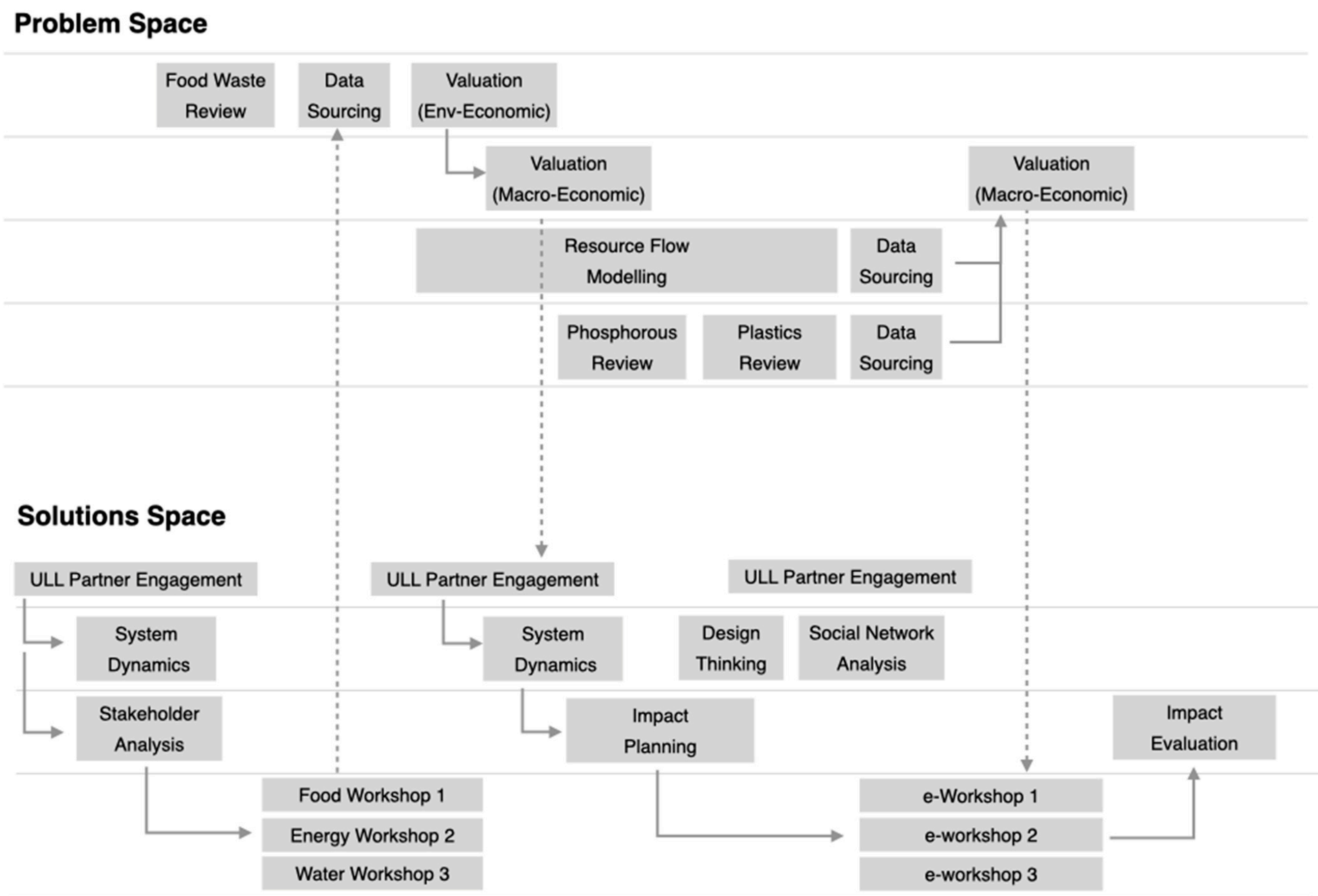

Figure 1. Disaggregated flow chart of the main research activities produced in the early stage of Phase 2 of the project.

While other issues were discussed and explored (e.g., phosphorous loss via sewage; energy inefficiency of anaerobic digestor)—see Supplementary Material—food waste emerged organically as the obvious focal point given the clear links, not only to food itself, but also energy (e.g., farming, transport, waste processing) and water (used in food production).

Given the focus on unintended consequences, and identifying potential losers (barriers) as well as winners, this approach draws on the concept of transition pathways [9]. In this conceptualisation, sustainable practices are encouraged ("building the new" and "adjusting and improving") and unsustainable practices phased out ("changing the rules" and "phasing out the old"). In order to set out realistic scenarios to test, the research team reviewed Bristol's One City Plan and extracted the environmental targets related to nutrient flows, sense-checking the approach through an economic-focused workshop and face to face meetings with stakeholder-partners before and after (Figure 2). Given the One City Plan includes 100s of targets in a wide range of areas and with considerable overlap between each, exclusion criteria were needed (see Supplementary Material).

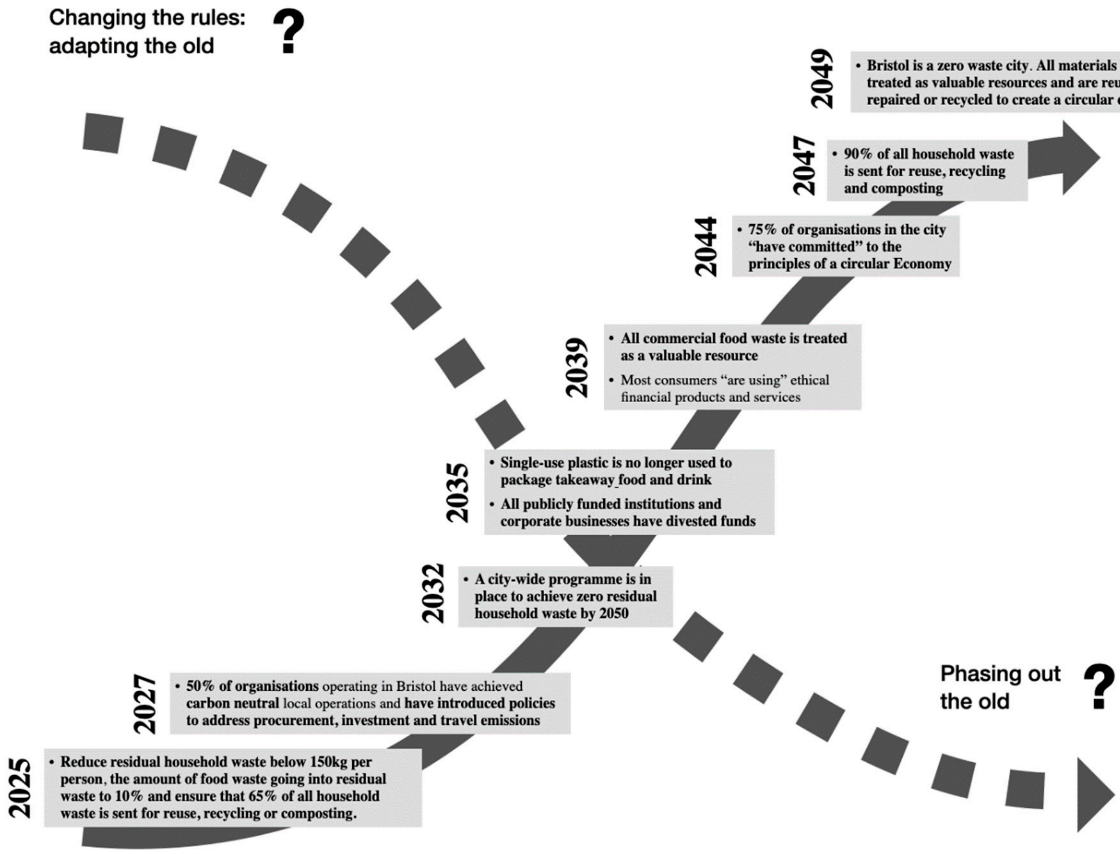

Figure 2. Illustrative depiction of Loorbach, Frantzeskaki, and Avelino's (2017) "x-curve" used at the workshop to illustrate how the Bristol One City Plan targets might scale up over time, while also highlighting the gap in understanding of who (where) the "losers" (barriers) might be (data One City Plan, Bristol City Council, 2021).

Following this elimination, we arrived at two main targets that linked most usefully to household and commercial food waste (and associated plastic contamination): (1) 2035: Single-use plastic no longer used to package takeaway food and drink; (2) 2049: Bristol is a Zero Waste City.

For the 2035 single-use plastic target, we assume that the single-use plastic used to package takeaway food and drink in 2035 becomes 5% of the 2015 level, meaning an average yearly reduction of 14%. We assume the 1000 tonnes of plastic in food waste in Bristol are all single-use plastic, which will be explicitly associated with the sector of plastic production in our valuation. For the 2049 Bristol "Zero Waste City" target, we adopt the WRAP target of 20% reduction by 2025 so that if the average yearly reduction rate continues, then the food waste in 2050 would be only 5% of the 2015 level, nearly zero. Hence, roughly speaking, the 2025 WRAP target delivers the Zero Waste City 2049 target. This applies for both households and commercial food waste.

2.2. Data: Household and Commercial Food Waste (HFW/CFW)

Local data were sourced primarily from the ULL partners. All of Bristol's household food waste (33,314 tonnes p.a., excluding sewage and compost) is collected by Bristol Waste, mainly in the brown food waste caddies and that disposed of in the large black bins ("residual" waste) [35], and transported to the treatment site at Avonmouth (Table 1). The household food waste in 2015 in Bristol is summarised in Table 2.

Table 1. Quantities and disposal method of avoidable and unavoidable household food waste in Bristol (from Eaton et al., 2021).

	Tonnes per Year
Recycled via caddy—avoidable	7868
Recycled via caddy—non-avoidable	5792
Food waste in residual—avoidable	16,194
Food waste in residual—non avoidable	3247
Sewer—avoidable	7773
Sewer—non avoidable	3331
Composting—avoidable	2487
Composting—non avoidable	1066
Other—avoidable	149
Other—non avoidable	64
Total	47,972

Table 2. Residential food waste in Bristol (source: own data).

Waste Types	Tonnes	Total Value (£ million)	Treatment Costs (£1000)
Total residential waste	77,761		
Of which: food waste	47,972		
- Avoidable	33,580	99.2	
- Recycled (AD)	13,660		478
- Residual (EfW)	19,440		1808
- Home composted	3553		
- Sewer	11,105		
- Other	213		

Nationally, the financial cost (of purchasing) the 4.4 Mt household food that is wasted (and could be avoided) is £13.0bn [35], which implies a price of c. £3000 per tonne HFW. Assuming this price is also for the 33,580 tonnes HFW in Bristol, then the total financial cost of the avoidable HFW in Bristol in a year is just under £100m (Table 2).

The site also receives currently about half of the city's commercial food waste (33,000 tonnes p.a.), which is contaminated with around 1000 tonnes of plastic each year, or 3.33% of total. Commercial food waste (CFW) is generated from several sectors including manufacturing, retail and wholesale, and hospitality and food service (HaFS). Based on Appendix 1 of WRAP (2017) [47], we could derive the financial cost per tonne CFW in each of the three sectors. Similar to household food waste, the financial cost of different food types is calculated as the wasted food quantities multiplied with corresponding prices. Hence, the financial cost is not the cost in the downstream for treatment of the food waste. Nationally, total financial (purchase) cost for almost 3Mt of commercial food waste is £4.5bn. If using Bristol data, that commercial food waste would be contaminated with 100,000 tonnes of plastic. Assuming the sectoral share of CFW in Bristol is the same as that in the UK, then we can estimate the total financial value (or direct economic cost) of the CFW in Bristol in a year to be c. £51m (Table 3).

Table 3. Commercial food waste and its financial cost in the UK and in Bristol (Wessex Water/GENeco data).

Commercial Food Waste Stream	Financial (p.a.)	Million Tonnes (p.a.)	Financial per Tonne	Financial (p.a.)	Tonnes
	£ bn	Mt	£/t	£ million	t
Region		**UK**		**Bristol**	
Manufacture	1.2	1.7	706	13.562	19,212
Retail & wholesale	0.8	0.3	2667	9.041	3390
Hospitality and food service	2.5	0.92	2717	28.253	10,397
Total	4.5	2.92	6090	50.856	33,000

Total value of avoidable food waste is based on a price of £2955/tonne derived from Table 1 of WRAP (2017) [47]. The cost of different food types is calculated, approximately, as the wasted food quantities multiplied with corresponding prices. Details are described in Chapter 8 of the Methods Annex Report [48,49]. Treatment costs of anaerobic digestion (AD) and Energy from Waste (EfW) are calculated as the treated waste multiplied with the median gate fees for Bristol 2019/20 (£/tonnes) in Table 1 of WRAP 2022 [50]. Energy from Waste (EfW) generates energy that can be used to generate more income from other activities. In this study, we do not include this. We currently have data available only for two types of treatment (recycled and residual). Where local data is unavailable, national data is used as a proxy. The unit cost of FW is assumed the same for Bristol and the nation. The total cost in Table 1 is only for Bristol as total residual waste in tonnes is based on Bristol data.

2.3. Developing Scenarios

The research team then used a variation the "rich picture" approach to test in a group setting with the Urban Living Lab stakeholders the potential changes in demand and supply side behaviours and linked policy options [51]. Drawing on the scenarios/futures literatures alongside standard approaches to macro-economic scenario development [37,38], this enabled scenarios to be set within the context of wider societal trends and considering transition implications (Figure 3). The group discussions revealed multiple potential focal areas, both demand-side (e.g., consumer behaviour change) and supply-side (producer/distributor behaviour change). Given the focus on residential food waste collection and the close engagement with Bristol Waste and their campaigns [52], a demand-side scenario emerged as the most appropriate with which to model the approach.

We hypothesised that a credible demand-side shift might occur following, for example, food prices rise, a sufficiently punitive tax on food waste collection, or raised awareness [53–55]. Consumers would then decide on whether and how to re-spend the savings. The exact cause of the demand-side shift is not essential at this stage, given the primary focus on testing the proof of concept. Clearly, there are important socioeconomic and inequality considerations too given food price rises and taxes on food waste collection will hit the poorest hardest. We did not seek to model the effects of, for example, higher food prices or re-spending on higher food prices. This (and other scenarios) is of course possible, but can be very complicated and multi-factorial. If higher food prices resulted directly in higher salaries and spending power for farmers, then they may have a similar effect as re-spending on, for example, tourism. Unfortunately, because of the "broken food system" this is not the case; a recent Sustain (2022) study has documented this for the UK and revealed how low the farmer labour share of profits is: below 1% for most food items [56]. If we use this as an example, there is higher spending for higher animal welfare standards in "certified organic" production or "free-range" production, but both have different premium prices. Organic food is not automatically a premium product with higher prices anymore, especially for bread or vegetables as fertiliser, and pesticide price hikes have affected this sector less. Supermarkets often also create premium lines (as they carry higher margin) without any change in the underlying production methods (as "organic" or "free-range" certification guarantees). Price hikes can be severe for certain products, e.g., tomatoes in UK greenhouses with fossil-fuel heating, or due to the professional harvest labour shortages, but these are short-term issues. A final complication is that supermarkets use below-production cost prices to attract customers; food prices are tools in the competition for market share, not necessarily a reflection of costs.

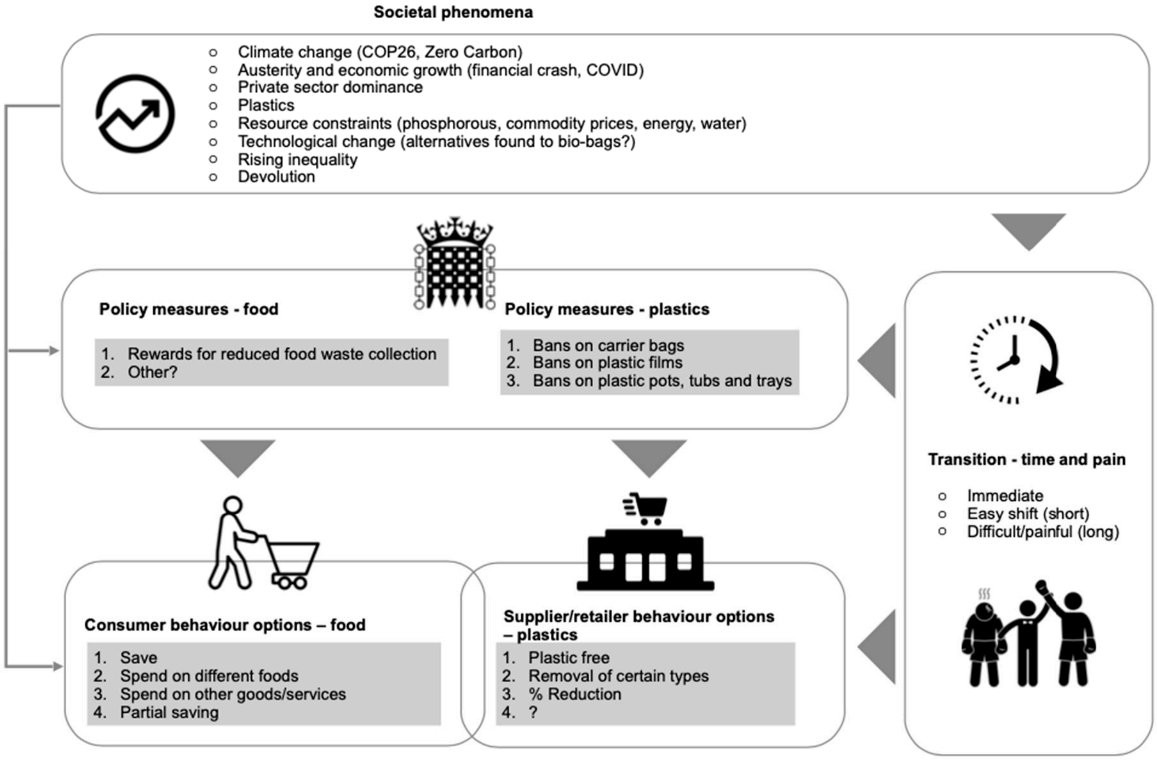

Figure 3. Combining a rich picture approach with scenarios literature in a group workshop setting to co-create a shared understanding of the food waste behaviour/policy space, in order to inform scenario selection (own data).

A demand-side shift will inevitably affect supply: the food producers (or suppliers) who generate the commercial food waste will therefore buy fewer inputs to produce the food due to the reduction in demand. The saved cost from lower input purchasing can also either be re-spent or not on other goods (which leads to further uncertainty, given the limits of modelling). Similarly, households who generate food waste will reduce food demand to save food cost, which can be either re-spent or not. The reduced demand for food and food feedstock further implies less production activities in related sectors, wherefrom the income of economic agents is generated. Figure 4 illustrates, in a simplified schematic, our understanding of the possible channels to impact on sectoral income resulting from food waste reduction.

As the production of food and other goods needs inputs from various sectors, such as food, energy, water, and tourism-related sectors, a change in the food market induced by demand-side food waste reduction disturbs the market of all these goods. As income is generated from the production and commercial activities of all these sectors, the food waste reduction would logically affect the income of any sector in the whole food supply chain. (The tourism sectors included here are a very rough aggregate of several sectors including Transport, Trade, Hotel, Rental service, and Travel agency; certain activities of these other sectors are clearly not for tourism.) In this study, an input–output method is used to estimate the interactions between sectors in the economy [57–60]. The input–output method captures the sectoral interactions in the whole economy and has been widely used to estimate macro-economic impact of an intervention measure. The method assumes that the same inputs are needed to produce any unit of goods in a given sector. The production technologies and economic interrelations are based on the 2015 economy of the UK [61], and the financial costs are calculated at the 2015 prices in the UK. The CO_2 emissions by sector in 2015 are used for baseline emissions [62].

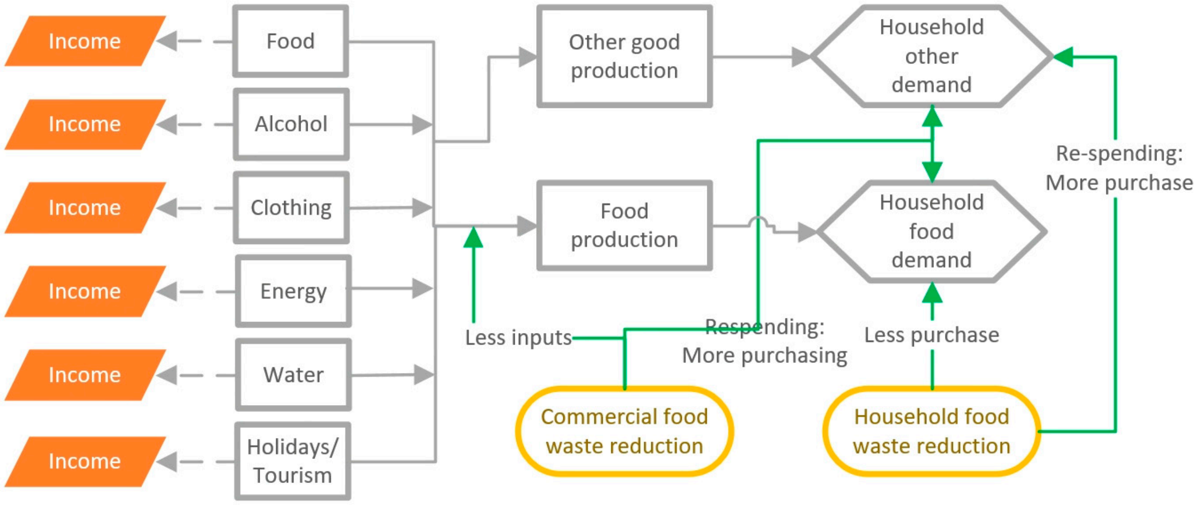

Figure 4. Preliminary conceptual flow hypothesis scoping potential food waste reduction links to sectoral income.

To consider the different reduction rates of food waste—current trends and more ambitious targets—with and without re-spending of the savings from reduced food waste, we arrive at four scenarios as shown in Table 4. In the two scenarios, N20 and R20, the 2.2% yearly reduction in food waste in Bristol corresponds to the national WRAP 2025 target, which roughly mimics the Zero Waste City 2049 target in Bristol if the trend continues until 2050. In the other two scenarios (N15 and R15), we assume a 1.6% yearly reduction in food waste, corresponding to the historical trend from 2007 to 2015.

Table 4. Assumptions for four scenarios: 20% or 15% food waste reduction, with and without re-spending on alcohol (note: if achievable, the 2025 WRAP target would deliver the Zero Waste City 2049 target).

Scenario Name	N20	R20	N15	R15
Food waste reduction (Bristol 2015–2025)	Food waste reduced by 20% during 2015–2025 (or 2.2% yearly) (WRAP 2025 target)	as N20	Food waste is reduced by 15% during 2015–2025 (or 1.6% yearly) (Following 2007–2015 trend)	as N15
Re-spending on other goods	No re-spending on alcohol, clothing, and tourism	Savings are re-spent on alcohol, clothing, and tourism	No re-spending on alcohol, clothing, and tourism	Savings are re-spent on alcohol, clothing, and tourism

The Zero Waste 2049 target is self-evidently a decades-long process, so the ideal approach to economic valuation in this case would traditionally be some form of dynamic model simulating the economic development until 2050, such as dynamic computable general equilibrium (CGE) models, though this is costly and unfeasible within the confines of this urban living lab project. Regardless, the validity of these models is also in question. In such models, it would be essential to consider population growth, technological progress, industrial transition, lifestyle changes, and interactions between economy and environment. Over time, the scale of food waste becomes smaller, which may likely imply stronger barriers, difficulties, and costs to reduce the same amount of food waste as before, though new technologies and efficiency improvement of the existing technologies may be developed to reduce costs of food waste reduction. In other words, there are so many variables that it is difficult, if not impossible, to ascertain reliably how different the economic cost and benefit of a food waste reduction would be in a future year compared to that in a recent year.

Rather than a complete and comprehensive analysis on the issue, this study does not attempt to estimate the economic value of the food waste over all the years given the complexity and uncertainty in the future. Instead, we consider the impact within one year in the process. The estimated economic cost and benefit is based on the economic situation in a recent year (2015) and to a large extent represents the possible yearly impact at the current stage. Based on the yearly results in this study, and simply assuming the same results for each year until 2050, we may roughly calculate the whole economic cost and benefit until 2050, though this has to be interpreted with caution given the considerable uncertainties mentioned above. The rationale for doing so, however, is to acquire a sense of scale of an issue, in order to understand whether it warrants further investigation. For example, in the "N20" and "R20" scenarios, where the 2025 WRAP target is assumed, meaning a yearly food waste reduction by 2.2%, the Zero Waste City 2049 target would be roughly achieved if the yearly food waste reduction rate continues every year until 2050. We are therefore seeking to understand, if the food waste in the 2015 economy in Bristol is reduced by 2.2%, to what extent the income of the sectors and economic agents would be affected. The yearly impact reported below is thus closer to a yearly approximation, although much lower than if we consider the total food waste value over decades. Two of the scenarios (N20 and N15) assume that economic agents do not re-spend the savings from the yearly food waste reduction on other consumer goods, while the other two scenarios (R20 and R15) assume the savings are re-spent to buy consumer goods by households. The savings in spending are calculated as the financial cost of the yearly reduced food waste. In the two scenarios with re-spending (R20 and R15), all the yearly savings are used by households to buy consumer goods.

3. Results

Table 5 shows the modelled changes in demand for domestically produced goods in Bristol due to a reduction in food waste in the four scenarios described above. In the re-spending cases (R20 and R15), there is an overall increase in economic activity, albeit a modest one, given new demand for goods, and especially to tourism. In the no re-spending cases (N20 and N15), there are much more significant reductions overall, mainly due to reduced food consumption, but across all modelled sectors. In the Scenario N20, the 2.2% reduction in food waste results in less demand for domestically produced goods at the level of £2 million per year for all the Bristol households (or less than £5 per person). Hence, in this scenario without re-spending, the reduced demand for domestically produced goods dominates the economic impact of the food waste reduction. However, if re-spending is considered in the Scenario R20, then the demand for domestically produced goods increases by £200,000 instead. This is because the re-spending is used for goods that produce a larger share by domestic producers, rather than imports. If we assume the re-spending case is the same for the years until 2050, then the demand in Bristol amounts to £6 million (0.2 × 30) during the 30 years from 2020 to 2050. Considering annual national food waste is 90 times Bristol's food waste, the increased demand due to the re-spending at the national level could amount to c. £18 million (0.2 × 90) per year and c. £540 million (6 × 90) from 2020–2050. Similar results are obtained at a smaller scale for the other two scenarios (N15 and R15). The demand for single-use plastic is also reduced in all the scenarios due to the 2035 target. The clothing and tourism sectors enjoy increased demand in the two re-spending scenarios (R20 and R15), but not alcohol, although certain re-spending is also allocated to alcohol. For all the other sectors, the demand (for all sectors other than food/plastic) is reduced in all the scenarios, mainly due to the food suppliers requiring less inputs to deliver food to the market.

Table 5. Yearly changes in demand for domestically produced goods in Bristol due to a reduction in food waste (£1000).

Scenario	N20 (20%, No Re-Spending)	R20 (20%, with Re-Spending)	N15 (15%, No Re-Spending)	R15 (15%, with Re-Spending)
Food	−1746.7	−1739.1	−1270.3	−1264.8
Alcohol	−24.0	−15.1	−17.5	−11.0
Clothing	−0.6	10.3	−0.4	7.5
Plastic	−4.7	−4.7	−3.4	−3.4
Energy	−18.7	−18.7	−13.6	−13.6
Water	−0.4	−0.4	−0.3	−0.3
Waste	−1.7	−1.7	−1.3	−1.3
Tourism (e.g., transport, hotel)	−84.6	2116.7	−61.5	1539.4
Others	−151.8	−151.8	−110.4	−110.4
Total	−2033.3	195.2	−1478.8	142.0

The changes in demand then influence the production and supply activities and further affect the income generated from these sectors, as shown in Table 6. The income impact confirms that the more (or less) demand for goods in a sector induces more (or less) production activities in the sector and thus more (or less) income. Notice that the aggregate impact on income in Table 6 is positively biased from the total demand of all goods, since the domestic producers spend less on imported inputs in their production activities, particularly in the food production sectors. In sectors other than food production; however, more imported goods are needed to produce goods to satisfy the changes in demand, leading to negatively biased income impact in these sectors in all the four scenarios. In the two scenarios without re-spending (N20 and N15), the aggregate income losses—annually, in Bristol—are far higher, reflecting that extreme case of a pure reduction in consumption (without any re-spending): £1.7 million and £1.2 million, respectively, nearly 60% of which are felt by the food production sector. This equates to £4.6 billion ($1.7 \times 30 \times 90/1000$) and £3.2 billion ($1.2 \times 30 \times 90/1000$) nationally, and £51 million (1.7×30) and £36 million (1.2×30) for Bristol from 2020 until 2050. While it may seem, therefore, that this policy is unviable, it does not account for any re-spending. When the re-spending is considered in the other two scenarios (R20 and R15), as with Table 5, the aggregate income is increased instead of reduced, albeit with a slightly smaller comparative difference. The income losses of the food sector are reduced slightly. The re-spending has been used on alcohol, clothing, and tourism. Only two of the three sectors (clothing and tourism) enjoy increased income rather than a decrease. The alcohol sector still suffers income losses since it has close relations to food spending, although the losses have been reduced to some extent due to the re-spending. The sectors we are not focused on (Others) also receive increased income, which is mainly induced by the increased activities due to the re-spending. The plastic and other sectors we focused on also benefit from the re-spending, but still suffer losses due to less demand for single-use plastic and inputs from food suppliers. The implications of this are discussed below.

The income impact can be further split into three elements—(i) taxes to the government; (ii) compensation of employees; and (iii) operating surplus to capital owners (Table 7)—by following their shares in total income shown in the sectoral input–output data in the national accounting [16]. Since the split is based on income shares, the impact on each income element in a sector has the same impact as that on sectoral income.

Table 6. Impact on income generated from production sectors—yearly income impact by sectors in the food supply chain (£1000).

Scenario	N20 (20%, No Re-Spending)	R20 (20%, with Re-Spending)	N15 (15%, No Re-Spending)	R15 (15%, with Re-Spending)
Food	−955.2	−921.5	−694.7	−670.2
Alcohol	−29.3	−21.1	−21.3	−15.4
Clothing	−1.4	5.5	−1.0	4.0
Plastic	−11.7	−5.8	−8.5	−4.2
Energy	−46.8	−20.9	−34.0	−15.2
Water	−2.5	−1.6	−1.8	−1.2
Waste	−4.3	−1.7	−3.1	−1.2
Tourism	−175.0	1186.5	−127.2	862.9
Others	−430.7	40.2	−313.2	29.3
Total	−1656.8	259.6	−1204.9	188.8

Table 7. Yearly impact on income received by resource owners (£1000).

Scenario	N20 (20%, No Re-Spending)	R20 (20%, with Re-Spending)	N15 (15%, No Re-Spending)	R15 (15%, with Re-Spending)
Taxes	−105.8	27.6	−77.0	20.1
- Food	−70.5	−69.8	−51.3	−50.8
- Alcohol	−1.3	−0.9	−0.9	−0.7
- Clothing	−0.0	0.1	−0.0	0.1
- Plastic	−0.4	−0.2	−0.3	−0.1
- Energy	−5.3	−2.1	−3.9	−1.5
- Water	−0.3	−0.2	−0.2	−0.2
- Waste	−0.4	−0.1	−0.3	−0.1
- Tourism	−8.7	99.2	−6.3	72.1
- Others	−19.0	1.7	−13.8	1.2
Compensation of employees	−986.8	138.6	−717.6	100.8
- Food	−595.7	−573.5	−433.2	−417.1
- Alcohol	−12.1	−8.7	−8.8	−6.3
- Clothing	−1.0	3.7	−0.7	2.7
- Plastic	−8.1	−4.0	−5.9	−2.9
- Energy	−14.4	−6.4	−10.4	−4.7
- Water	−0.7	−0.5	−0.5	−0.3
- Waste	−1.9	−0.8	−1.4	−0.6
- Tourism	−111.3	718.1	-81.0	522.3
- Others	−241.6	10.6	−175.7	7.7
Gross operating surplus	−564.2	93.4	−410.3	67.9
- Food	−289.0	−278.2	−210.2	−202.3
- Alcohol	−15.9	−11.5	−11.6	−8.3
- Clothing	−0.4	1.7	−0.3	1.3
- Plastic	−3.2	−1.6	−2.3	−1.2
- Energy	−27.1	−12.4	−19.7	−9.0
- Water	−1.5	−1.0	−1.1	−0.7
- Waste	−2.0	−0.8	−1.5	−0.6
- Tourism	−55.0	369.1	−40.0	268.5
- Others	−170.1	27.9	−123.7	20.3
Total	−1656.8	259.6	−1204.9	188.8

- Tax revenue: Here we consider only the changes in the taxes levied during production (e.g., not consumer taxes paid by households and import tariffs). In all four scenarios, tax revenue collected from the production activities in a year is reduced to some extent, except the clothing and tourism sectors, which pay more taxes in both re-spending scenarios (R20 and R15). The largest loss of £0.1 million is found in the N20 scenario where the WRAP 2025 target is achieved, and re-spending is not considered. Even in this scenario, the total loss of tax revenue is trivial compared to the reduced demand for goods of £2 million. If regions other than Bristol copy the same pattern in the coming decades, then the loss at the national amounts to £270 million (0.1 × 30 × 90) from 2020 to 2050 in this worst scenario (N20). Although taxes from only two sectors increase, the increase overweighs and makes the total taxes increase slightly in both re-spending scenarios (R20 and R15);

- Labour income: Labour income reduces overall—represented by "compensation of employees"—in all four scenarios except the Clothing and Tourism sectors in the two re-spending scenarios (R20 and R15). When households re-spend their savings (from reduced food spending), the labour income increases in those other sectors due to increased production activities; in particular, the relative labour intensity of the tourism service industries means that the increase in labour income in the sector benefitting from the re-spending is strong enough to cancel out the decrease in the food sector;
- Income of capital owners: We assume an operating surplus from production activities is obtained by capital owners. As indicated by the gross operating surplus in Table 6, capital owners also receive losses when no re-spending is considered (N20 and N15). This is natural as less production activities reduce the utility of already equipped capital assets within the food and other sectors. On the contrary, when re-spending is considered as well (R20 and R15), capital owners receive more income as a whole, mainly due to more operating surplus from tourism and other sectors we are not focused on.

The results show that, under these scenarios, tax revenue and income of labour suppliers and capital owners suffer losses in the cases without re-spending and gains slightly from re-spending, mainly due to the income in the tourism sector. This is mainly due to the structural differences between the food and tourism sectors. The implications of this are discussed briefly below.

Changes in CO_2 emissions are shown in Table 8. The calculations for each sector are based on the same CO_2 emissions from any unit of the goods produced in the sector. In other words, more or less production in each sector leads to more or less CO_2. At the aggregate level, less emissions are obtained in the scenarios without re-spending (N20 and N15), while somewhat higher emissions are obtained in the other two scenarios with re-spending (R20 and R15), mainly contributed by the high-emission sectors of energy and tourism (mainly transport). The largest reduction in CO_2 emissions is 450 tonnes per year in the N20 scenario, where the energy sector contributes almost the same as the food sector since the energy sector is a high emission sector, although the reduced energy demand is only 5% of the reduced food demand as shown in Table 4. In the two scenarios with re-spending, the whole economy enjoys an income increase together with some positive downstream environmental benefits, albeit with higher CO_2 emissions as a whole due to greater production activities in tourism-related sectors (mainly transport) and the energy sector.

Table 8. Changes in CO_2 emissions by sectors in the food supply chain (tonnes).

Scenario	N20 (20%, No Re-Spending)	R20 (20%, with Re-Spending)	N15 (15%, No Re-Spending)	R15 (15%, with Re-Spending)
Food	−168.6	−158.0	−122.6	−114.9
Alcohol	−9.1	−6.5	−6.6	−4.7
Clothing	−0.6	1.8	−0.4	1.3
Plastic	−4.3	−2.1	−3.1	−1.5
Energy	−179.4	−68.5	−130.5	−49.8
Water	−0.4	−0.3	−0.3	−0.2
Waste	−1.1	−0.4	−0.8	−0.3
Tourism	−41.4	436.0	−30.1	317.1
Others	−38.9	−4.6	−28.3	−3.4
Total	−443.8	197.3	−322.8	143.5

4. Discussion

The aim of this research activity was to understand (a) the consequences of achieving Bristol's One City Plan food waste targets, and specifically who might lose out in these transition pathways; (b) linked carbon and other socioenvironmental implications; (c) linked policy implications; and (d) the usefulness of this approach. By developing new valuation methods—in this case by integrating macro-economic modelling with participatory scenario planning alongside systems approaches—we hoped to enable city decision-makers to consider more fully the impacts of their urban projects and policies on community (and planetary) health and wellbeing.

Calls for alternative means of valuation that account for ecological public health or planetary health are not new [63,64], and over the last decade, the calls have been increasing substantially [65–69]. Yet assigning value to these "intangibles" and, more specifically, linking those valuations to critical decision-making, is not straightforward [11,12,35]. There are many parts of the decision-making "system and systems" that need recalibrating in order to better understand and promote urban health and the sustained functioning of socioecological systems [70–72]. As underlined above, the uncertainties inherent in this exercise are significant (e.g., much will depend on changing patterns of behaviour), and are open to critique. However, we argue that it does not necessarily negate the usefulness of this exercise [73]. The method employed is not intended to be a traditional cost-benefit analysis. We are interested instead in developing new approaches to valuation across complex systems, and understanding whether or not we can acquire a credible sense of scale of socioenvironmental impact in different areas [11,12,24,35].

As regards the consequences in different sectors of achieving Bristol's targets of no single-use plastic by 2035 and zero waste by 2049, our models suggest overall that:

1. If there is a reduction in overall food consumption (either no or reduced re-spending), this would lead to an equivalent and relatively significant decrease in economic activity, which would inevitably impact the food sectors and associated employees the most, given the relatively higher employment rates in the food sector (retail, logistics) compared to the other sectors;
2. If the savings are fully re-spent on alcohol, clothing, and tourism services (for example)—which logic would suggest is far more likely than a no re-spend scenario—it would lead to an overall increase in economic activity, with associated benefits to those sectors' employees and capital owners in addition to tax revenues (albeit a comparatively more modest uplift compared to the reduction).

In other words, while it may be possible—likely, even—that there could be a modest net benefit to the economy overall from a transition to a reduced food waste future, there would likely be significant risks facing food producers/suppliers due to income reduction, both to capital owners and their employees. If accurate, this implies that there would likely be significant blockages at the national level due to countervailing forces from the "second face of power" [74,75]. As with the food producers, suppliers, and distributors, so too with the waste processors: a transition such as this would also present challenges to those profiting from energy generation from food waste (e.g., industrial anaerobic digestors) [76]. Notably however, Wessex Water did not express much concern in relation to this, suggesting that, were a significant reduction to manifest, they could easily source excess food waste from elsewhere, which seemed a reasonable assumption given current levels of food waste, the perverse incentives, and systemic inertia. It is worth noting that there are significant concerns, both nationally and internationally, with regards the inefficiencies of using remote bio-crops, requiring considerable transport, to power anaerobic digestors [77]. These inefficiencies add to the overall narrative, but the point of this paper is to underline that these structural changes in the labour and capital market imply considerable associated transition costs (and barriers).

Our first finding may also explain why there is so much food waste in the current system: because "productionism"—i.e., producing food with the aim of wasting it to produce more food—makes economic sense under the current macro-economic valuation.

To understand this clearly is critical for any zero waste target as the macro-economic landscape most likely needs changing more radically (e.g., via taxation, revaluations of non-market outputs); only then zero waste might be possible.

A key additional point is the temporal aspect, which is critical in terms of transition pathways, i.e., while the total value of food waste is large when considered over one year, the gradual reduction over decades implies that the yearly impact to achieve the One City Plan targets would be far more moderate and, potentially, manageable.

With regards to the socioenvironmental implications of this study, and drawing on Eaton et al. (2022) [35], the environmental benefits of reduced food waste appear to be relatively small based on current estimates of the shadow (or market) prices of different environmental pollutions. This suggests that wasted food is seen currently—perversely—as a benefit to the economy. In other words, there is currently no sufficient economic motivation for agents to reduce food waste. This position is supported given an unchanging status quo in this space. In the future, the shadow (or market) prices of the environmental pollution might increase dramatically (e.g., CO_2 prices in the cases of considerable global warming), and then the environmental benefits might become large enough to overweigh the macro-economic losses in income. Equally, as outlined in (3), if food prices would increase significantly and this had no negative impact on lower income consumers (e.g., because there is a basic income in place), this "added value" would instead go mainly into increased salaries for farmers to spend in the rural economy. In such a scenario, zero food waste would be more likely as it values food and those who produce it more than society does currently.

With regard to the policy implications of these city targets, there are multiple headline messages. At a local and national level:

1. Firstly, and perhaps most importantly, the current macro-economic landscape appears to be promoting clear and harmful resource inefficiencies, suggesting government policy and market failure;
2. Secondly, central government intervention would likely be necessary to prepare for potential income losses in the food and plastic production sectors caused by the reduction in food waste, including those employees who may need improved employment opportunities or support (e.g., entrepreneurship in high value food production), even if gradual over a given period;
3. Thirdly, given the potential benefits to other sectors and overall potential increase in domestic economic activity (with full re-spending), support for better food, aiming for zero waste, may be sought from those who substantially benefit outside the food sector.

Given that structural changes such as these—i.e., supporting whole sector transformation—appear to rely largely on national government intervention, there are clear limits to what may be possible at the local level, yet this knowledge may in itself help to steer local action. Table 9 shows a preliminary SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis presented to the Bristol Food Waste Action Group—the city's key food waste actors—with suggested strategy considerations [78]. For example, given that benefits, especially environmental, accrue nationally and internationally, the justification for city-level action could be seen as a weakness or threat. On the other hand, these estimates are based on a demand-side shift, which cities have some control over (e.g., local campaigns). Evidence of national and international benefits might be useful in negotiating with central government in advance of spending reviews, or in positioning cities as urban living labs capable of testing innovative potential solutions.

Table 9. Initial considerations presented to the Bristol Food Waste Action Group through a preliminary SWOT analysis.

Strengths/Opportunities	Weaknesses/Threats

• Cities have some (albeit limited) influence, over consumer behaviour (e.g., local campaigns/awareness raising);
• Potential benefits nationally might be used in negotiating with central government: e.g.,
  ◦ Spending reviews;
  ◦ Bristol as city innovator for Govt.
• Better awareness of macro-challenges may incentivise local action.
	• Reliance on national level intervention.
	• Cities have such limited resources (inc. fiscal autonomy).
	• Benefits—especially environmental—accrue nationally and internationally, so justification for city-level action is arguably weaker.

With regards to whether or not this approach is useful, we propose that, by modelling hypothetical scenarios of two extreme cases, as with future scenario planning, we can improve our understanding of at least some of the possible income impacts by sectors and economic winners and losers. However, given the limited scope of the exercise, the approach inevitably needs further development and testing. For example, while findings related to income losses in the food and plastic production sectors and income losses of labour providers are relatively robust, in order to provide a more robust estimate overall, market prices assume no changes before and after a reduction in food waste, which is unrealistic. There are also considerable uncertainties given the decades-long timespan that it covers. A more robust evaluation would estimate the impact every year based on a well-designed baseline scenario considering how the economy develops over time, and discounting future impacts. Even so, it would depend heavily on the specific assumptions behind the baseline scenario such as technological development, household behaviour change, sectoral structure change, available natural resources, and change in renewable policies. Even within one year, as we have considered in this study, our estimate is only an approximation as we assume the food waste reduction does not have effects on market prices and thus economic agents do not adjust their consumption and production as responses to any potential (likely) price change. The substitution between goods and inputs in production and consumption must also be introduced to better model the macro-economic responses to a reduction in food waste. Adding another approach such as a computable general equilibrium (CGE) model may be a useful next step.

With further development and testing, therefore, if our integrated valuation approach continues to show promise, it may be that it contributes substantially to the topics of focus in this journal: the promotion and sustaining of urban health, the achievement of the United Nations 2030 Agenda for Sustainable Development, and the associated Sustainable Development Goals, especially SDG 3 and 11.

5. Conclusions

This paper sets out high-level macro-valuations, both positive and negative, that may result from achieving Bristol's food waste reduction targets, with a focus specifically on (a) sectoral income and (b) climate (CO_2). Scenarios are derived through extensive stakeholder engagement through the newly formed urban living lab, participatory scenario development, and rich picture mapping, and with a core focus on Bristol's One City Plan food waste targets. The exercise was by no means a comprehensive macro-economic study, and it was never intended to be. The aim was to integrate different, complementary approaches from a range of disciplines—economics, sociotechnical futures, soft systems, participatory action research—in order to develop and test a new way of valuing socioecological outcomes. The goal was to offer some initial insight into potential barriers and opportunities in order to (a) help achieve the city's targets; and (b) sense check whether this approach may be useful (i.e., worth further time/resources for development). Undoubtedly this approach needs further development and testing, but with that, and if validation continues, it should—we hope—contribute to the promotion and sustaining of urban health and waste reduction strategies.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15076004/s1, Document S1: Further details on the WASTE FEW ULL Consortium and Bristol Urban Living Lab including: ULL partner organisations, research activity undertaken within the Bristol ULL, a note on sewage and energy, the problem with biodegradable caddy liners, and exclusion criteria used in target selection; rationale for sector selection for options "not re-spending" and "re-spending"; Table S1: ONS—Detailed household expenditure by disposable income decile group; Table S2: SIC Categories and GHG emissions—re-spend selection; Table S3: Mapping of SIC sectors to aggregate sectors in this study.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the patient(s) to publish this paper.

Data Availability Statement: The data presented in this study are available via the links/references provided or in the Supplementary Material. Data were also obtained from Bristol Waste and Wessex Water/GENeco and may be available with their permission.

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