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Article

Socioeconomic Impacts of Food Waste Reduction in the European Union

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Abstract: Food waste is a global multidimensional problem, with economic, social, and environmental dimensions linked to sustainable development. This study analyses the socio-economic and pollution effects of reducing food waste in the European Union. The food waste reduction scenarios analysed cover all segments of the supply chain from primary production to household consumption. Using the economy-wide model SAMmodEU, the impact of the scenarios is analysed in the context of the whole economy. Most scenarios analysed demonstrate positive socioeconomic effects in terms of a slight increase in gross domestic product and increasing employment. The multicriteria analysis indicates that the best overall performance is achieved by reducing food waste in the foodservice. It is recommended to focus on behaviour in policy design, thereby reducing food waste both in food services and in households and ensuring positive socioeconomic impacts.

Keywords: food waste; food loss; cleaner production; economic impacts; input—output analysis; social accounting matrix

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1. Introduction

According to the most common understanding, food waste and loss can be described as food not used for its primary purpose, i.e., not eaten. However, defining these concepts more precisely is a rather complicated task, as edibility depends not only on the nutritional value of products but also on cultural and social norms [1]. There are several concepts explaining food waste and food loss. The Food and Agriculture Organization of the United Nations (FAO) distinguishes between food waste and loss depending on where potential food is lost from the supply chain. Food waste occurs at the retail trade stage and at final consumption, while food loss is considered until (but not including) the sales level [2]. The latest data on the progress with sustainable development indicators shows that globally 13.8% of food is lost, 17% of the food available to consumers is wasted, while 8.9% of the global population is undernourished [3]. In this context, the concept of ‘loss’ refers more to various inefficiencies in the production processes, while ‘waste’ is related to behavioural issues. It is noticed that food loss in the upstream segments of the supply chain is more prevalent in low-income countries, while food waste in distribution and consumption stages is a feature of medium and high income countries [4]. FAO’s definition of food loss is very much in line with the United States Environment Protection Agency (EPA), which defines food loss as ‘unused product from the agricultural sector’. Moreover, EPA distinguishes between ‘food waste’ and ‘wasted food’ as the latter term allows stressing that usable product is wasted. At the same time, ‘food waste’ may refer to spoiled food and inedible parts of food (e.g., rinds and peels) [5].

However, the common feature of food loss, wasted food, and food waste is that food is not used as intended. This idea is expressed by the European Union who identifies food waste along the whole food supply chain, starting from harvesting (the production of primary food) and ending with final consumption [6]. Such an approach contrasts to some extent with the FAO's distinction between food waste and food loss discussed earlier, but it allows for a greater focus on the inefficiencies in the food supply chain. This article also follows this European concept and broadly defines food waste as the removal of food from different supply chain segments. It can therefore be argued that the distinction between food waste and food loss, which is oriented towards the supply chain segments, disappears in this case and the concepts are treated as proximate. This allows the same methodological principles to be applied to the analysis of both food loss and food waste (according to the FAO definition) and allows for objective comparisons to be made.

The reasons why edible products are removed from the food supply chain may be diverse, including aesthetics, 'use by' dates, economic reasons [7], or inefficient production processes. They all lead to the same result: food is not consumed for its intended purpose, and often does not yield valuable products either.

Another difficulty in identifying food waste is when food is transferred to other product supply chains, which is not considered to be either food waste or food loss [1] because, in this case, food is used for other, presumably socially beneficial purposes, even though the benefits may in some cases be meagre compared to the use for food. This, however, leads to a certain relativity, where the use of even a small amount of added value (e.g., in the production of landfill biogas) could already be considered as valorization and loss avoidance. To avoid such uncertainty, we focus on waste reduction in this research instead of evaluating alternative ways of utilising food. Additionally, food waste is considered in a broad sense, acknowledging its possible occurrence along the supply chain. As food waste is related to the environmental impacts of food production, in the upstream supply chain, food waste reduction can result from cleaner production practices, while in the downstream supply chain and in consumption it is more related to the sustainability of consumer behaviour.

As a multidimensional problem, food waste is widely discussed by researchers from different points of view. First, food waste is perceived as an environmental problem as it makes up the large share of municipal solid waste [8]. Although not intuitively expected, food waste reduction might increase overall pollution due to a rebound effect when positive economic gains turn to output increases in more waste generating activities. It has been estimated that rebound effects can reduce greenhouse gas emissions by as much as 38% less than would be the case if macroeconomic rebound effects were not considered [9]. The same principle is valid for other targets that are put by countries in the context of the sustainable transition: if food waste reduction results in increased energy consumption in some other industries, direct calculations about energy savings in the food industry would not be valid in the context of countrywide energy efficiency targets. Second, food waste has multidimensional social impacts as it vividly highlights the fragmentation of society. Although the economic impacts of food waste are widely acknowledged along with its environmental impact [10], most of the research is relatively limited in scope and fails to reflect the full scale of the effects. Different variations of life cycle analysis are used to compare the food waste management alternatives. Life cycle assessment (LCA) and life cycle costing are two well-established methodologies for environmental and economic impacts; they also provide the grounds for social and socioeconomic impact assessments in social LCA [11]. However, an especially attributional life cycle analysis is restricted by system boundaries that are relatively narrow in many studies [8]. Economic assessments are often limited by cost calculations [12] and fail to provide an economy-wide analysis, which is pivotal for covering the full scale of impacts. Economic impacts of food waste reduction in one segment of the food supply chain have cascading effects over the entire chain [13]. Therefore, food waste reduction at the consumption stage might also impact food loss in other segments and, respectively, an increased efficiency of food production would have broader impacts across the whole supply chain. From this viewpoint, it might be argued that narrow system boundaries may also limit the estimations of the environmental consequences as macroeconomic rebounds also considerably impact the environment [9]. Another limitation is that life cycle costing research is generally oriented to existing food waste management instead of its prevention [10,14], even though waste prevention should be regarded as superior to any waste management system — a system which still has its negative impacts [15]. Food waste prevention in respect to leftovers, consumption practices related to suboptimal or expired food, and shopping practices that prevent food waste are each identified as the most promising intervention areas to reduce food waste in households [16]. Similarly, in the upstream segments of the supply chain, cleaner production practices that enable more efficient use of food can benefit both from an environmental and a socioeconomic point of view.

Although estimates of potential impacts would provide additional valuable arguments for food waste reduction and guide policymakers and business representatives, few studies analyse the socioeconomic impacts of reducing food waste [17] and report mixed results. The modelling with the applied general equilibrium model MAGNET found that reduced food waste in households caused decreased food and agricultural production, increasing household savings and had a minor negative impact on the gross domestic product (GDP) [18]. The complex impacts of food waste reduction also include expected change in energy consumption and contribution to the achieved energy efficiency targets [19]. However, this contribution might be limited by rebound effects if the benefits of food waste reduction cause increased activity levels in the areas with high energy intensity. Economy-wide analysis therefore has clear advantages in assessing the net effects of reducing food waste. Using a linear CGE model, the analysis for several European countries shows a negative economic effect of food waste reduction, the magnitude of which depends on the economic structure of the countries considered, the food waste scenarios [20], and other conditions [21]. The importance of economic structure is confirmed also by a study for the Finnish region of South Ostrobothnia, where food waste reduction provides positive economic impacts [22]. As Spang et al. (2019) noted, further studies considering food waste impacts on the broader economy might be valuable in assisting policymakers in formulating strategies to reduce food waste [23].

In this study, filling in identified gaps in the existing literature, the socioeconomic implications of food waste reduction in different supply chain segments are analysed broadly economywide. In contrast to some previous works, we consider scenarios covering food production stages and consumption. As the analysis covers not only socioeconomic impacts but also pollution (relating output changes to pollution levels in different industries allows for revealing impacts on overall pollution), all three sustainability dimensions are covered in this research. A multicriterial analysis is involved in the final stage of the study to rank scenarios by their integrated sustainability impact.

The remainder of this paper is structured as follows: Section 2 presents the research methodology and data sources; Section 3 provides the research results. Section 4 finalises the article by providing conclusions and discussing possible policy implications.

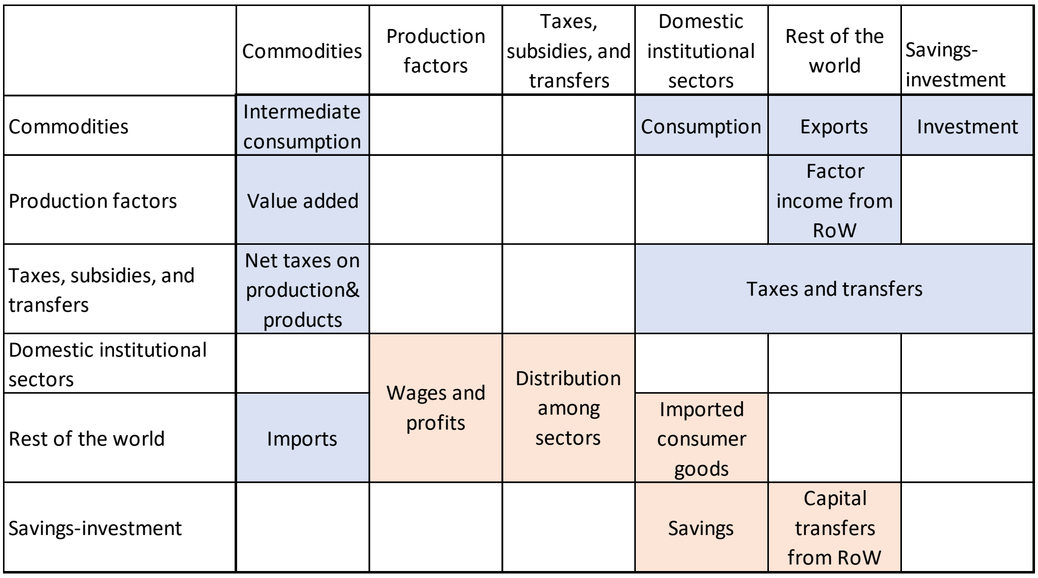
2. Methodology and Data

In this study, scenarios of reducing food waste are expressed as changes in the structure of the economy, which are quantified by analysing statistical data. These scenarios are then modelled in an economy-wide model to reveal their socioeconomic impacts. Multidimensional results are integrated using multicriteria analysis, while sensitivity and uncertainty analyses are carried out to assess the impact of uncertain factors.

2.1. Research Methodology

The analysis employs a social accounting matrix (SAM) model SAMmodEU that covers all the most important economic relationships. This model can be considered an extension of the conventional input–output model, allowing us to overcome some of its limitations and cover indirect and induced impacts of changes in the economy. The model's main advantage is its flexibility to reflect changing economic structures in a transparent and easy-to-interpret conceptual framework.

The basic structure of the social accounting matrix using SAMmodEU is depicted in Figure 1.



	Commodities	Production factors	Taxes, subsidies, and transfers	Domestic institutional sectors	Rest of the world	Savings-investment
Commodities	Intermediate consumption			Consumption	Exports	Investment
Production factors	Value added				Factor income from RoW	
Taxes, subsidies, and transfers	Net taxes on production& products			Taxes and transfers		
Domestic institutional sectors		Wages and profits	Distribution among sectors			
Rest of the world	Imports			Imported consumer goods		
Savings-investment				Savings	Capital transfers from RoW	

Figure 1. Structure of the social accounting matrix.

In the SAMmodEU model, the intersectoral relationships are modelled in a way common to demand-driven quantity input-output models [24], but because a complete social accounting matrix is used, the modelling is extended to express full economic impacts.

As in a conventional input–output model, linear Leontiev production functions are used to express production in all industries. First, the input coefficients are calculated for each product considering structural changes in industries defined in the scenarios. Then production and consumption are balanced by solving a linear equation system [24]. This gives only a partial equilibrium solution, so an iterative routine balances the entire social accounting matrix. In other words, changes in the income of institutional sectors affect their demands and transfers, further impacting outputs and intermediate consumption in the industries. This process is repeated iteratively until a complete equilibrium is reached and the social accounting matrix is balanced. The difference between the initial equilibrium (baseline SAM) and the new equilibrium reached is considered an economy-wide impact of the structural changes analysed. Most economic impacts can be calculated directly from social accounting matrices, while social and environmental indicators are evaluated using additional data related to relevant indicators in the SAM.

2.2. Modelling Data Sources

The data sources used for the social accounting matrix are also indicated in Figure 1. The FIGARO [25,26] database's 2022 edition [27] is used to create the product-by-product input-output table for the EU (the SAM segments colored in blue in Figure 1), while Eurostat's data on non-financial transactions (a dataset called *nasa_10_nf_tr* [28]) is used to cover the remaining parts of the social accounting matrix (orange segments in Figure 1). Both data sources are available to the public through open-access conditions.

Although the FIGARO database is completely balanced, this is not fully the case with the entire SAM compiled using data from different sources. While preparing an EU-wide social accounting matrix employed in this research, social accounting matrices for most EU countries were created, and their consistency was checked. Some inconsistencies exist due to the use of the most recent data (e.g., when the data on non-financial transactions were updated after preparing and publishing the FIGARO dataset) and, possibly, other reasons. Although inconsistencies are usually not of a critical scale, the created SAM was balanced minimising deviations from the initial version and ensuring that all balances are kept. The final version of the SAM used in the simulations presented in this article is available online [29].

2.3. Scenario Setup

As the initial idea of the study was to assess the impact of reducing food waste in different segments of the supply chain, the definition of the supply chain and the identification of the level of food waste in the different segments is essential. Figure 2 summarises the food supply chain stages analysed. In order to ensure methodological consistency, the identified stages of the food supply chain correspond to the methodology set out in Annex III of the Commission delegated decision (EU) 2019/1597 [6].

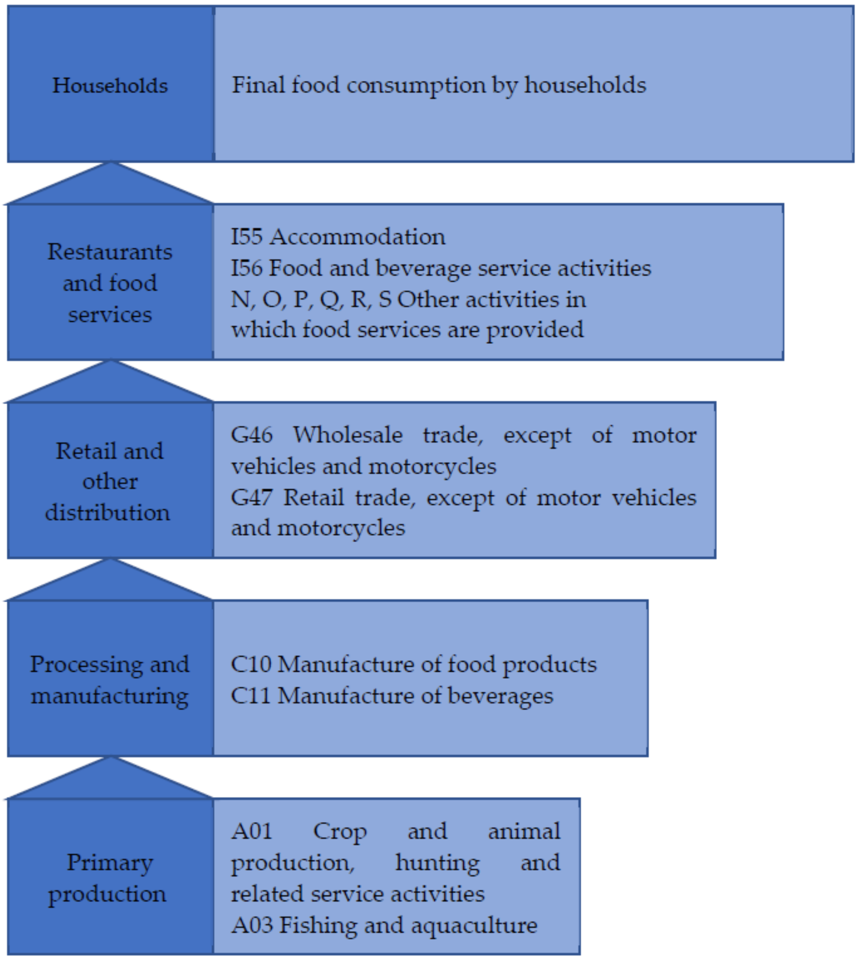


Figure 2. Stages of the food supply chain in which part of food is lost or wasted.

The EU Fusions data [30] and Eurostat statistics on food waste (*env_wasfw* dataset [31]) can be considered as the most consistent and sufficiently reliable data sources for building an EU-wide scenario. Although the Fusion project presents statistics for 2012 and covers 28 EU member states, including the United Kingdom, the assumptions used in the Fusion project are also valuable for justifying scenarios for 2020, based on Eurostat data on food waste in the EU. Figure 3 shows the per capita amounts of food waste in the EU in different segments of the supply chain in 2021 and 2020.

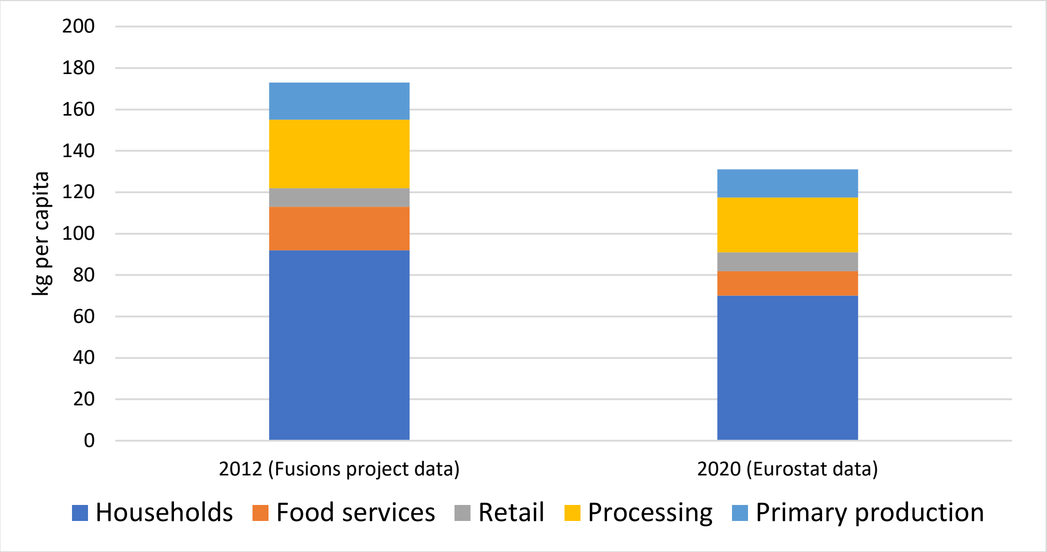


Figure 3. Estimates of food waste in the EU [30,31].

As can be seen from the figure, the structure of wasted food by segments of the supply chain is quite similar in both sources, but the overall volumes were reduced from 173 kg per person in 2012 to 131 kg per person in 2020. The most pronounced changes are recorded in households (92 to 70 kg per person) and restaurants and food service (21 to 11.8 kg per person). This can be attributed both to real changes and to the impact of the COVID-19 pandemic (it has not only affected household food waste patterns [32,33], but the lockdown also limited the time restaurants could be open in 2020) and to the development of methodologies for estimating the volume of food wasted. The pattern of food waste in the different phases of the supply chain is broadly in line with the distribution found in other studies [17] and can therefore be used for further analysis.

Food waste data for 2020 are further used to build the scenarios analysed. Fusion project data on the share and cost of edible food are used to calculate the value of edible food waste in different segments of the supply chain (the latter adjusted by a factor of 1.1 to reflect inflation). Table 1 presents food waste values used in the scenarios.

Table 1. Assumed food waste reduction values under scenarios considered.

	Total Food Waste in 2020, Million Tonnes [31]	Edible Waste Share [30]	Edible Food Waste Value, Billion EUR
Households	31.3	0.6	72.9
Food services	5.3	0.59	10.8
Retail	4.1	0.83	10.3
Processing	11.8	0.5	9.7
Primary production	6.1	0.5	1.3

The estimated value of edible food waste provides the grounding for the scenarios considered. In contrast to previous studies, we construct scenarios based on assumptions about the edibility of food, rather than simply defining the proportion of food wasted. While this does not reflect the actual potential for reducing food waste, it allows for a better assessment of the value of wasted food. As with food waste estimations [34], the actual potential of food waste reduction depends on the area considered and various local circumstances. A case study on Italian pasta production shows that it is already in line with circular economy principles as just a little part of food is lost during its production. However, the consumption stage demonstrates certain potential for waste reduction [35].

Intermediate scenarios could be formulated to assess such factors but would not show the full impact of reducing food waste.

Table 1 shows that the *Households* scenario has the highest value of food waste to be reduced (EUR 72.9 billion), the *Primary production* scenario has the lowest value (EUR 1.3 billion), while the *Food services*, *Retail*, and *Processing* scenarios have similar values (about EUR 10 billion). It should also be noted that the Households scenario differs substantially from the others in that it represents a change in consumption due to food waste reduction. In contrast, the other scenarios reflect production efficiencies through the introduction of cleaner production practices. This leads to higher factor incomes in the relevant activities, while the *Households* scenario offers consumers more opportunities for consumption and savings.

3. Results and Discussion

The main modelling results cover the key dimensions of sustainability: economic (impact on GDP), social (impact on employment), and environmental (impact on waste and greenhouse gas emissions).

3.1. Economic, Social, and Environmental Impacts of Food Waste Reduction in Different Supply Chain Segments

The main indicator used to measure the impact of reducing food waste is the change in GDP. The results of the calculations for the scenarios considered in this work are presented in Figure 4. In addition, a relative indicator describing the relationship between the change in GDP and the reduction in the value of wasted food is also presented. In a sense, this relative indicator describes the efficiency of food waste and shows how much of the reduction in waste is translated into additional value added to society in each scenario considered.

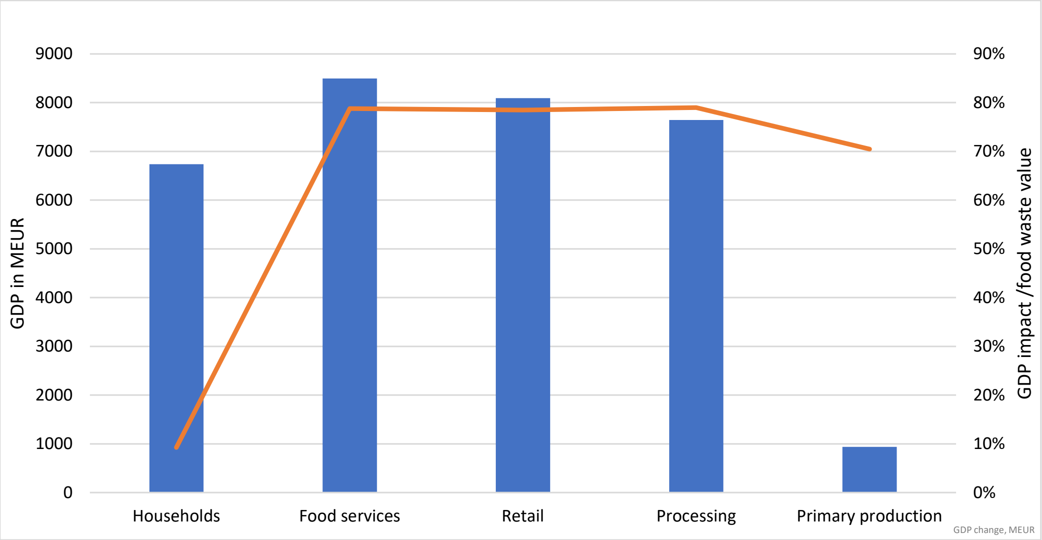


Figure 4. GDP impacts of food waste reduction scenarios.

As can be seen from Figure 4, all scenarios except *Primary Production* show a fairly similar impact on GDP, ranging between EUR 6.7 billion and EUR 8.5 billion (this can be translated to 0.05–0.07% of GDP). The lower impact of the *Primary production* scenario is primarily due to the lower value of wasted food and the interpretation of food in this supply chain segment. In terms of the ratio of the change in GDP to the value of the reduction in food waste, the scenarios representing all segments of the food supply chain show a range of 70 to 79%, while for consumption, the ratio is only 9%, as in fact, the reduction in food waste translates into the consumption of other products. In this case, the main immediate effect is a reduction in value added in the supply chain segments directly linked to food supply and an increase in value added in other economic activities depending on the substitution in consumption. It should be noted that both substitution and income effects play an important role here. Reducing food waste in households alone creates the potential to consume more of other goods, and if the value added is rising, increased income creates the potential for further growth in consumption.

The modest GDP increase is, in principle, in line with the previous research on food waste reduction in households. While CGE modelling shows an increase in household savings and a minor GDP reduction [18], our model returns a small GDP growth related to the assumption about the fixed saving rate in households. The overall results obtained (low GDP growth, negative impact on agri-food economic activities) align with a study in the Finnish region of South Ostrobothnia [22], but it should be noted that the baseline conditions of the scenarios used in the present research are different, and no direct comparison is possible.

Although the GDP impact in the *Households* scenario is slightly lower than in other scenarios (except *Primary production*), it must be noted that the setup of this scenario is different from that of all the rest. In the *Households* case, food waste reduction value is proportionally distributed among all the consumption categories, and saving represents unchanged overall households' preferences. If the behavioural change included not only food waste reduction but also change in other preferences, the results may significantly fluctuate depending on the type of products whose consumption is increasing. Our additional experiments show the GDP fluctuations in the *Households* scenario from EUR −176 billion in the case where not-wasted food value is used for the consumption of refined petroleum products to about EUR 55 billion in the case when not-wasted food value is used to increase demand of domestically-oriented employment or human health activities. It should be noted that similar observations also apply to household income growth which, in principle, might enable some changes in demand patterns. Therefore, household behaviour and sustainability of consumption play an important role not only in the *Households* scenario but also in the other scenarios considered.

The calculated employment impacts are shown in Figure 5.

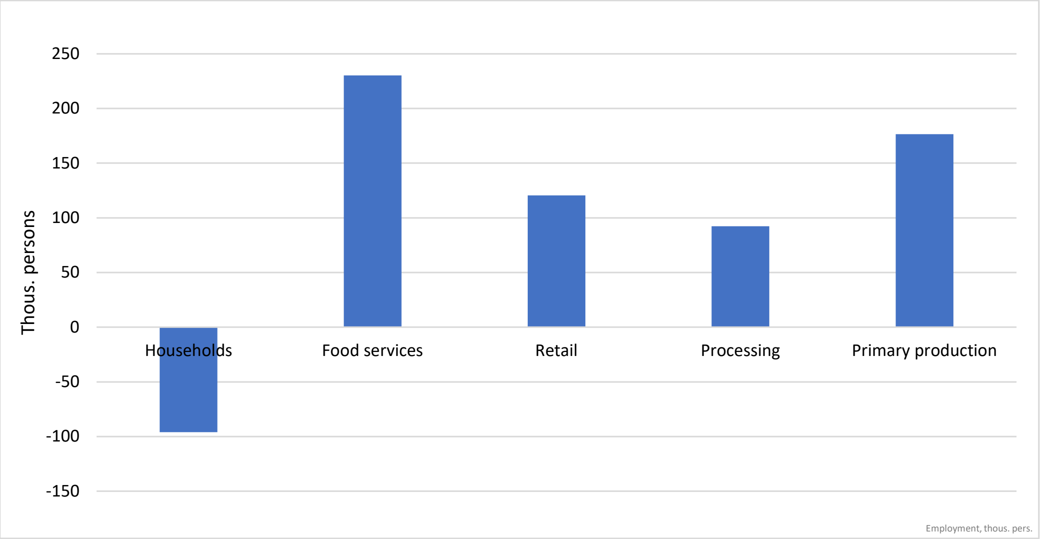


Figure 5. Employment impacts of food waste reduction scenarios.

In contrast to the GDP impacts, employment impacts demonstrate considerable variation. The *Households* scenario shows adverse employment impacts mainly because of employment reduction in the agriculture and food processing industry, which is not compensated by increasing employment levels in other economic activities. The net impact on the EU level is −95.9 thousand employees, which makes −0.046% of the total employment in the baseline. In the rest of the scenarios, employment impacts are positive ranging from an additional 92.2 thousand jobs in the *Processing* scenario to 230.2 thousand jobs in the *Food services* scenario. The positive employment impact is closely related to the assumption that the benefits of cleaner production practices in reducing food waste are distributed between capital and labour, contributing to their implementation. Thus, the implementation of cleaner production practices typically results in a labour boost in that industry, as intermediate consumption is partially replaced by labour and decreasing employment in the food industry and agriculture. So close a relationship between agriculture and the food industry is determined by the fact that nearly half of the agricultural output is used in the food industry as intermediate consumption within the EU.

Methodologically, the question of the impact of declining domestic demand on export volumes of particular products is an important issue, but in order to avoid overestimating the socioeconomic effects of avoiding food waste, the modelling assumed that export demand remains stable. However, it should be noted that a different treatment of exports (e.g., assuming that a reduction in the intermediate consumption of agricultural products in the food industry would increase their export volumes) would also imply an increase in the positive effects on both employment and the GDP.

Another important methodological aspect is the degree of labour mobility between economic activities. The SAMmodEU model has no constraints on labour mobility, which may exist in reality not only due to differences in skills but also due to differences in geographical specialisation. On the other hand, introducing cleaner production practices and spreading more sustainable consumption is a long-term process, and their socioeconomic impacts should therefore be seen in a long-term context which may eliminate the above-mentioned mobility restrictions.

Cleaner production and sustainable consumption practices have an impact on the output of various economic activities and hence on the environmental damage they cause, even if technologies and relative levels of pollution in other sectors of the economy do not change. This study assesses total waste amounts and greenhouse gas emissions as the representatives of pollution impact.

Figure 6 shows the change in total waste mass (covering both hazardous and non-hazardous) for the different scenarios. The results include both direct waste reduction assumed in each scenario and the results of economy-wide modelling, which either amplify or mitigate the initial effect.

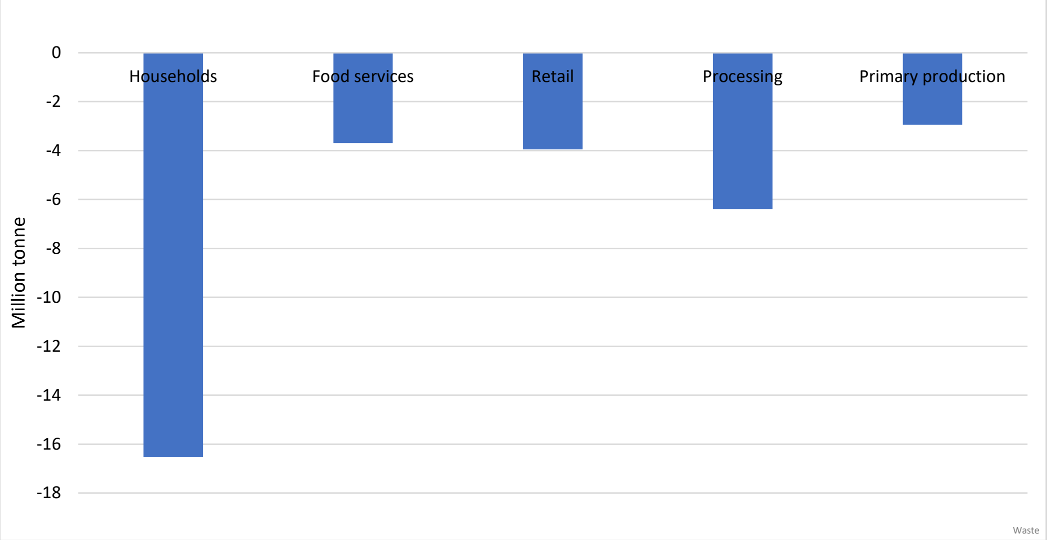


Figure 6. Changes in waste generation.

As the food industry itself is not an exceptionally highly polluting economic activity, a reduction in household food waste may also lead to an increase in pollution if the consumption of products from more polluting economic activities increases. This situation is illustrated by the results of the *Households* scenario, where the initial food waste reduction of 18.8 million tonnes is mitigated to 16.5 million tonnes due to an increase of other waste types. This can be seen as a rebound effect, where a reduction in waste in one area leads to a rise in another. It is also observed in the primary production scenario, while the scenarios representing the other supply chain segments show a trend of strengthening the initial waste reduction.

Greenhouse gas emission impacts are shown in Figure 7.

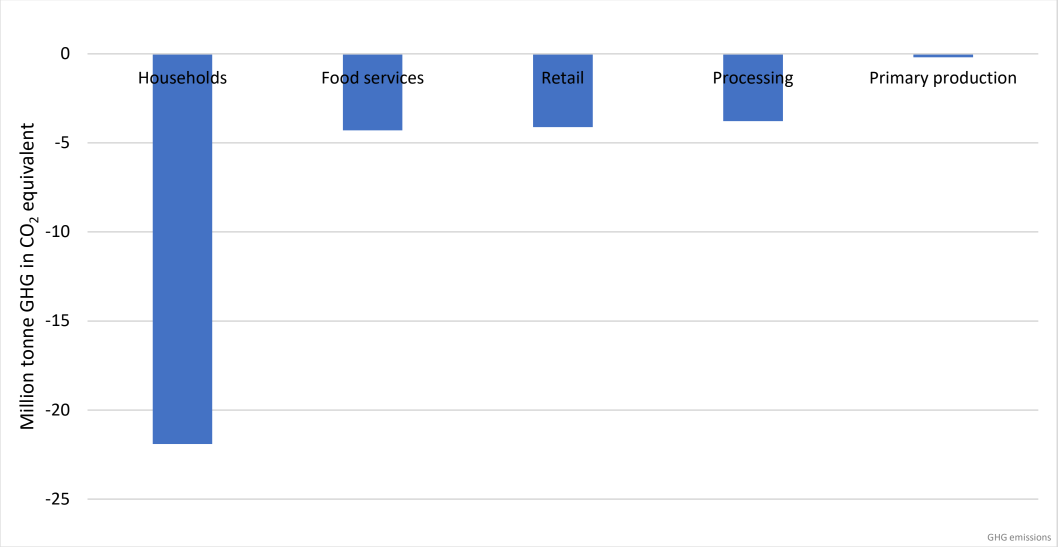


Figure 7. Changes in greenhouse gas emissions.

Estimates of greenhouse gas changes show very similar trends. The *Households* scenario shows the largest reduction in GHG emissions, with the most considerable reduction in food waste, manifesting through the supply chain as a reduction in agricultural output. Considering that agriculture is among the most significant GHG-emitting economic activities, we obtained a relationship between the decrease in food waste and the level of emissions.

The results are comparable to the work of other researchers, who show that a 50% avoided reduction in consumer food waste would mean a 4% reduction in agricultural emissions (in the scenario with valorisation of food waste for pig feed, the reduction in emissions is only 0.2%) [36]. Another relevant study obtained an about 3.5% reduction in agricultural emissions due to the avoidance of food waste in households by 50% with 1% compliance cost (if compliance cost increases to 5%, the amount of emissions reduces even more considerably) [18]. In the *Households* scenario of the present study, which simulates the avoidance of edible waste (or a 60% reduction in food waste in households), agricultural emissions are reduced by 4.3%. The results are, therefore, quite similar. Some of the differences are due to both the modelling methodological aspects and the food waste reduction scenarios, which in turn are related to the different estimates of the quantities of waste generated.

In summary, the *Households* scenario shows the best results in the environmental domain, the *Food services* scenario shows the best economic and social (employment) results, the *Primary production* scenario also has a significant impact on employment, and the *Retail* and *Processing* scenarios have a certain impact on all the aspects analysed.

3.2. Multicriterial Analysis of Food Waste Reduction Scenarios

In order to compare all scenarios, the multicriteria analysis integrates the results of the scenarios in different areas. In the initial stage of the analysis, the economic, social, and environmental domains are given equal weighting, ensuring that all sustainability pillars are reflected. In the environmental dimension, air pollution and waste generation are given equal weight. The normalisation of the results of the individual dimensions leads to integrated sustainability estimates that can theoretically fall between 0 and 1, with 1 representing the most favourable results.

The results of the calculations are presented in Figure 8.

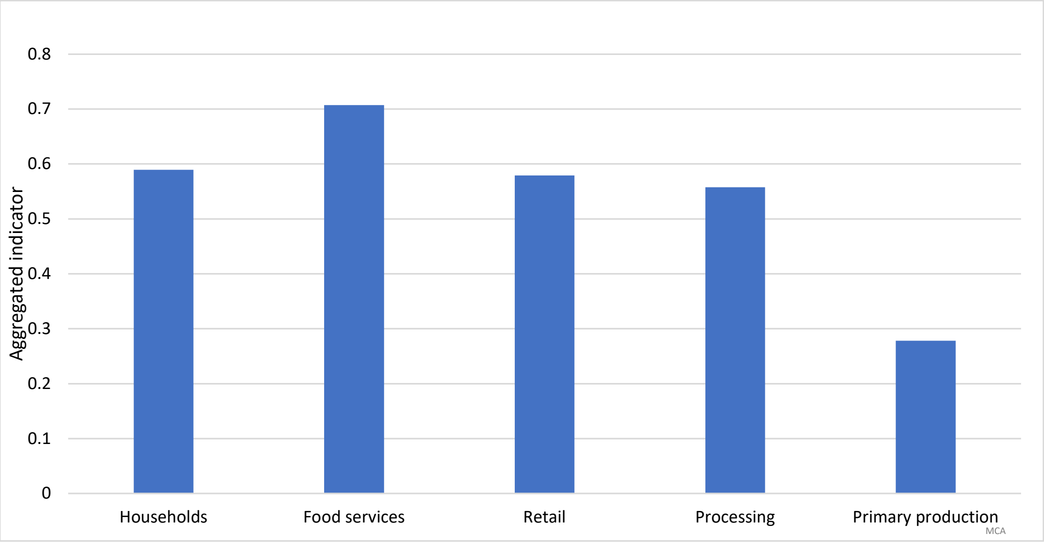


Figure 8. Integrated ranking of scenarios analysed.

As can be seen from the figure, the *Food services* scenario shows the best aggregate performance (0.71), followed by the *Households* (0.59), *Retail* (0.58) and *Processing* (0.56) scenarios, while the *Primary production* scenario has the worst rating (0.28). These results are largely due to the fact that the value of wasted food in this segment of the supply chain is considered to be lower than in the other segments analysed. As mentioned above, this is also related to certain interpretative issues, such as the EU principle of considering food waste as only food that has already entered the supply chain. On the other hand, there are some uncertainties in estimating the value of wasted food, which in this work has been carried out based on the assumptions of the Fusion project.

Although we consider food waste reduction primarily as an efficiency increase in this research, it also provides new business opportunities due to valuable resources that may be recovered and used in various industries to close the supply chain loop [4]. On the other hand, the overall impact of reducing food waste could vary considerably depending on business models and valorisation strategies. As previous studies have shown, valorisation of food waste can introduce significant changes in the estimates of all the indicators considered [36], which is why the analysis of complete scenarios, including both food waste reduction and reuse strategies, plays an important role. The results of the present research show that the positive socioeconomic impacts of food waste reduction also imply that food waste valorisation strategies should be formulated taking into account their sustainability impact.

3.3. Sensitivity and Uncertainity Analysis

The main reasons for the uncertainty in the calculation results are the weighting of the individual sustainability dimensions [8] and the value of wasted food. These factors are also addressed in the sensitivity and uncertainty analysis. The analysis uses multipliers to adjust the values previously set. This generates five sets of random numbers where the distribution of values follows a uniform distribution between 0 and 1 and five sets of random numbers where the distribution of values follows a normal distribution with a mean equal to one and a standard deviation equal to 0.2. These correction factors are used to create adjusted sets of scenarios for which simulations are carried out and integrated indicators are calculated. Multiplying the assumed prices of wasted food by the correction factors gives a price distribution with a mean that is consistent with the assumption and a standard deviation of 20% of the price value. Meanwhile, the weights of the different factors are additionally calculated based on the proportions between the values generated. This way, although the original parameter values are uniformly distributed, the distributions of the weights are close to normal.

The results of uncertainty analysis are shown in Figure 9.

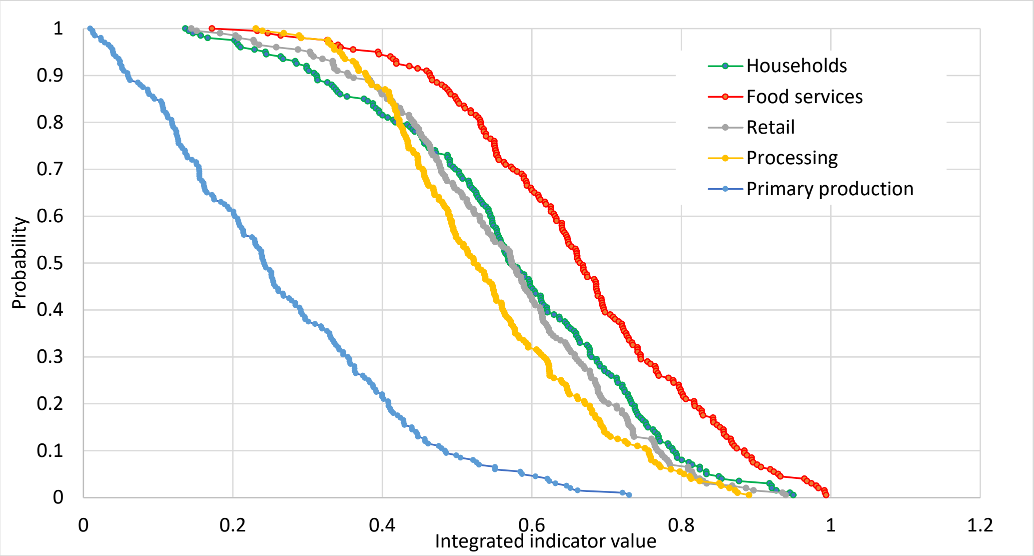


Figure 9. Uncertainty of integrated scenario ranking.

As seen from the figure, the Food services scenario remains the best scenario among assessed, even when considering parameter uncertainties. The *Primary production* scenario shows the worst performance, while the *Household*, *Retail* and *Processing* scenarios show very similar results. The uncertainty ranges for all estimation results are quite wide, taking into account the possible changes in the weights of the sustainability domains and the assumptions made about the value of wasted food and, thus, the magnitude of changes. It is, therefore, essential to assess the factors that have the most significant influence on the uncertainty of the scenarios of food waste reduction. The results of the sensitivity analysis are presented in Table 2.

Table 2. Spearman correlation coefficient between sensitivity factors and scenario ranking.

	Households	**Food Services**	**Retail**	**Processing**	**Primary Production**
Economic impact factor	0.141*	0.19 *	0.442 *	0.373 *	−0.307
Employment impact factor	−0.705	0.466 *	0.177 *	0.135 *	0.804 *
Environmental impact factor	0.538 *	−0.72	−0.592	−0.529	−0.406
Waste factor	0.199 *	−0.204	−0.083	−0.02	−0.135
Air pollution factor	0.012	−0.044	−0.016	−0.069	0.065
FW cost in households	0.108	0.094	0.014	0.108	0.194
FW cost in food services	−0.209	0.366 *	−0.307	−0.276	−0.107
FW cost in retail	−0.174	−0.029	0.536 *	−0.162	0.042
FW cost in processing	−0.089	0.003	−0.165	0.539 *	0.049
FW cost in primary production	−0.01	−0.038	−0.017	−0.109	0.166 *

* Significant at 95% confidence level.

In the integrated assessment, the weights given to the different sustainability domains influence the ranking of scenarios. For most scenarios, the weighting of economic impact and jobs created is statistically significant. The impact of the environmental impact indicator is not statistically significant in most scenarios, despite the rather high correlation coefficients. This can be attributed to the environmental impact assessment being a twofold exercise, involving changes in waste and air pollution (greenhouse gas emissions). Although all the scenarios examined reduce environmental pollution, their performance in these two dimensions is slightly different, which reduces the importance of weighting environmental impacts.

The limitations of the study are largely determined by methodological choices and data availability. The SAMmodEU model used in the analysis has its own limitations and does not endogenously model price changes, which could affect the results. Assumptions about the cost of wasted edible food in all segments of the supply chain, except households, have a significant impact on the integrated assessment of the scenarios (as costs increase, so does the potential positive impact of reducing food waste). Given these results and the challenges of estimating the value of wasted food [30], future research should pay significant attention to specifying the costs of wasted food and to the granularity of food groups. A more detailed picture would allow for a better integration of life cycle assessments into the analysis of the socioeconomic effects of food waste reduction and provide more detailed results. The analysis of specific cleaner production practices or business models in order to identify their socio-economic effects could be identified as a very promising avenue for further research.

4. Conclusions

Cleaner food production practices and more sustainable consumption in the EU positively impact economic growth through increased resource efficiency. This is achieved through the simultaneous operation of several channels of spillovers in the economy, the analysis of which is enabled by an economy-wide model.

All the scenarios analysed demonstrate positive GDP outcomes. Still, the magnitude depends on the amount of food waste in each segment of the supply chain and the nature of the segment. Although households have the highest potential for reducing food waste, the impact on GDP of more sustainable household food consumption depends strongly on other consumption decisions that can lead to rebound effects (in the extreme case, the largest negative impact on EU GDP is if the reduction of food waste leads to higher consumption of petroleum products). Other segments of the supply chain scenarios with economic growth may also exhibit similar variations in terms of the alternative uses of the household’s increased income.

The employment effects of the scenarios examined differ depending on the employment and productivity trends in different economic activities. While reducing household food waste may reduce employment levels, the other scenarios contribute to employment growth. However, this result highly depends on the initial assumptions about the need for production factors to reduce food waste in economic activities.

In an integrated assessment of the impact of the scenarios, the *Food services* scenario demonstrates the best overall performance. Considering that food waste in this segment of the supply chain is primarily driven by consumer behaviour (e.g., food ordered in a restaurant but not eaten) and that behavioural factors play an even more important role in household food waste, it can be argued that policy measures to reduce food waste should also primarily target behavioural factors.

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