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From surplus to sustainability: The role of legislation in reducing climate impact from Swedish bread waste

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ABSTRACT

Food waste infers considerable environmental, social, and economic consequences. While previous research has focused on interventions at the supplier-retailer interface to reduce surplus, this paper explores the reduction potential in applying legal instruments and evaluates the climate benefits of enforcing four different policy measures: 1) *Prohibiting Unfair Trading Practices*; 2) *Advancing Redistribution of Surplus*; 3) *Enforcing Best Available Technology*; and 4) *Legally binding reduction targets*. Applied to the case study of bread in Sweden, the results clearly show that, through the enforcement of binding regulations or market-based mechanisms, surplus could be reduced by 6–50 %, while also lowering climate impact with up to 18 % compared to the current system. The results illustrate how Sweden can optimize its bread supply chain through regulatory and market-based strategies, with applicability on an international scale. These findings also highlight the potential in combining legislation and economic incentives to optimize the conventional bread supply chain, for reduced waste and improved surplus management. By demonstrating the benefits of enforcing different legislations and policy measures, the results can be used to further develop and enforce targeted policy recommendations and legislations for reduced food waste. While the scenarios explored are specific to the bread supply chain, the insights gained are applicable to other perishable food sectors facing similar waste management challenges.

1. Introduction

Food waste has been recognized as an increasingly pressing global concern, with estimates suggesting that 20 % to 60 % of food production is wasted annually (FAO, 2019). Given the environmental, economic, and social consequences of wasting food, it is often of high priority for policymakers and stakeholders, both at the national and global levels. One of the targets set by the United Nations' Sustainable Development Goals (SDGs) is to halve food waste at the consumer and retail levels by 2030 (United Nations Environment Programme, 2024). In the European Union, about 20 % of food produced is wasted or lost (European Commission, 2020), prompting the implementation of various policies, including the Waste Framework Directive 2008/98/EC (2008), the EU Platform on Food Losses and Food Waste (European Commission, 2016), and the Farm to Fork Strategy (Grant and Rossi, 2022). The EU Directive 2008/98/EC specifies prevention as the top priority, followed by reuse, recycling, recovery, and lastly disposal. The *food waste hierarchy*, initially developed by Papargyropoulou et al. (2014), often serves as a framework to establish priority levels for activities, laws, and management pathways related to food waste in the EU. In comparison, other regions such as Latin America, the U.S., and Southeast Asia have pursued alternative policy mixes, ranging from voluntary industry agreements to binding landfill bans (Guterres, 2020; Pasarín and Viinikainen, 2022), offering valuable contrasts to the European experience. Similar hierarchical approaches have also been developed, such as the U.S. Environmental Protection Agency's Food Recovery Hierarchy and Japan's Food Recycling Law, though these differ in emphasis, scope, and enforcement mechanisms. Although policy measures are key in advancing food waste

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reduction goals, as voiced by van Zanten and Putintseva (2025), the implementation of transformative policies often remains insufficient.

Despite the often high edibility of surplus food generated before the household level, only a small fraction is currently directed to human consumption in Sweden, either via donations or price reductions (Johansson, 2021; Sundin et al., 2022; Hultén et al., 2024). Meanwhile, food insecurity continues to rise (Sundin et al., 2023). One barrier to recovering a higher share of edible food in Sweden is the perception that surplus food is primarily a waste issue. This means that it is mainly evaluated through environmental and economic lenses. As a result, existing policies and infrastructure have led to about 32 % of collected food waste in 2018 being used for biogas production (Johansson, 2021), despite the priority level agreed on at the EU level (European Commission, 2016). These challenges are not unique to Sweden or the EU; on the contrary, most countries globally face comparable tensions between stated prevention priorities and the reality of waste management practices. This imbalance, with states prioritizing recycling over prevention, was first noted by Mourad (2016), who emphasized the preference for *weak prevention actions*, those focusing on efficiency improvements while neglecting rebound effects and long-term risks, over *strong prevention actions* that address resource limitations and promote sustainable production and consumption. Thyberg and Tonjes (2016) later introduced the concept of the *Prevention Paradox*, highlighting the contradiction between the publicly declared preference for prevention and the actual responses by industry and governments, which centre on managing rather than preventing food waste. Giordano et al. (2020) further underscored the imbalance in both policy and research, which disproportionately place responsibility for food waste on consumers. They noted a lack of effective measures targeting food supply chain actors, with most efforts focusing instead on consumer actions and food donations. Messner et al. (2020) also contributed to the discussion by expanding on these contradictions, reaffirming the misalignment between declared priorities and implemented strategies.

When considering volume, bread has been identified as one of the leading contributors to food waste at both retail and household levels (Albizzati et al., 2019; Hultén et al., 2024), with various factors causing surplus and waste (Goryńska-Goldmann et al., 2021; Soni et al., 2022). The annual consumption of bread in Sweden was 2023 estimated at roughly 50 kg per person (Swedish Board of Agriculture 2023), accounting for roughly 28 % of the total energy intake (Lind, 2018). Notably, 90 % of the bread sold at retail in Sweden is distributed under take-back agreements (TBAs), which hold the suppliers responsible for both producing the bread and also distributing and managing unsold products at retail (Brancoli et al., 2019). The remaining 10 % consists of non-TBA products, such as private label products. For these products, the retailer assumes financial responsibility for unsold products, including their disposal as waste. Previous research indicates that the TBAs applied for bread may be a hotspot for waste generation, since it limits the potential and incentives for stakeholders to reduce waste generated at the retail stage (Eriksson et al., 2017). The high wastage of bread in terms of quantity is also observed in other countries, for instance, Italy, Germany, Finland, and Austria (Nikolicic et al., 2021; Pietrangeli et al., 2023). In their study assessing the climate impact of supermarket food waste, Brancoli et al. (2017) concluded that bread was among the products with the highest environmental footprint at the retail level. Moreover, the short shelf life of perishable food products such as bread and bakery products is also a key factor influencing waste (Trento et al., 2021; Riesenegger and Hübner, 2022). Canali et al. (2017) identified multiple drivers for food waste at the retail level and highlighted how amending inefficient legislation could play an important role in food waste reduction. Also addressing policy, Eriksson et al. (2023) evaluated the potential gains of enforcing the best voluntary practices. They concluded that, when applied to the public catering sector in Sweden, enforcing the national Environmental Code on the food chain could reduce waste generation by up to 76 %. Their study did not address how this would influence surplus bread, although this sector is of high concern since bakeries, along with dairies and the meat industry, represent over 50 % of the total agricultural output value in Sweden (Ghosh and Eriksson, 2019).

With respect to mitigation measures for food waste in Europe, Priefer et al. (2016) argued that all stages of the food chain should be accounted for. Aslam et al. (2024) further emphasize the importance of reducing food waste to reduce the climate impact, which is a target specified in SDG 12.3 (United Nations Environment Programme, 2024). To effectively reduce food waste, adequate policies must be implemented and ultimately enforced to motivate stakeholders to take action (Derambarsh, 2024). These policies can include market-based mechanisms that raise the costs associated with food waste, binding regulations that enforce specific behaviors, or a combination of both approaches. Many legislation and policy measures implemented globally are designed to ensure fulfillment of SDG target 12.3 of halving food waste. Experiences from countries like France, which mandates food donation by retailers (Albizzati et al., 2019), and South Korea, which enforces compulsory food waste recycling with volume-based fees (Cho and Kang, 2017), illustrate how regulatory design can influence outcomes. While much previous research has focused on interventions at the supplier-retailer interface to reduce surplus (Mena et al., 2011; Brancoli, 2021) or improving transportation (Weber et al., 2023) and resource management (Bartek et al., 2025), the perspective of how much food waste can be reduced through different policy instruments is missing. Previous studies have also assessed food waste policies in general for a Swedish context (Eriksson et al., 2023), but the implications of enforcing different legislative instruments across specific value chains remain unclear. In fact, public policy often falls short of its intended outcomes due to the inherent complexity of the systems it aims to govern, which challenges the traditional reliance on predictability and control in policy design (Mueller, 2020). This also reflects a broader challenge, voiced by Mourad (2016), of disconnection between the intent of a legislation and its practical outcomes.

This study addresses key research gaps by quantifying the environmental impact of four policy scenarios, using the bread supply chain as a case study due to its status as a staple food with high waste rates. Bread serves as a representative example to assess how targeted legal interventions might drive broader sustainability in the food system. The study models potential waste reductions and associated climate impacts under four policy instruments, applied to the Swedish market. The aim is to identify the effectiveness and limitations of legal tools in reducing food waste, thereby informing priorities in the transition to a more sustainable food system.

2. Material and method

2.1. Scenario development

The *Baseline* scenario reflects the current supply chain in Sweden for pre-packaged bread sold under TBA, as this represents most bread sold at retail. Within this system, suppliers are responsible for forecasting, stocking shelves, removing unsold bread from retailers, and managing the pathways used for waste or surplus. Today, unsold bread is managed through various pathways, primarily directed toward energy production via anaerobic digestion and incineration, while a smaller share is redirected to animal feed or donations via assistance organizations. This baseline scenario serves as a reference point for four alternative scenarios designed to reflect policy changes introduced in a Swedish context (Fig. 1). The developed scenarios, including: 1) *Prohibiting Unfair Trading Practice*; 2) *Advancing Redistribution of Surplus*; 3) *Enforcing Best Available Technology*; and 4) *Legally Binding Reduction Targets*, were designed to simulate the impact of market-based mechanisms, regulations, or legislation, aimed at reducing the surplus food or utilizing it more efficiently. The first three scenarios aim to capture a specific legislation approach, while the fourth was designed to capture the common objective of reaching the SDG target 12.3 of halving global food

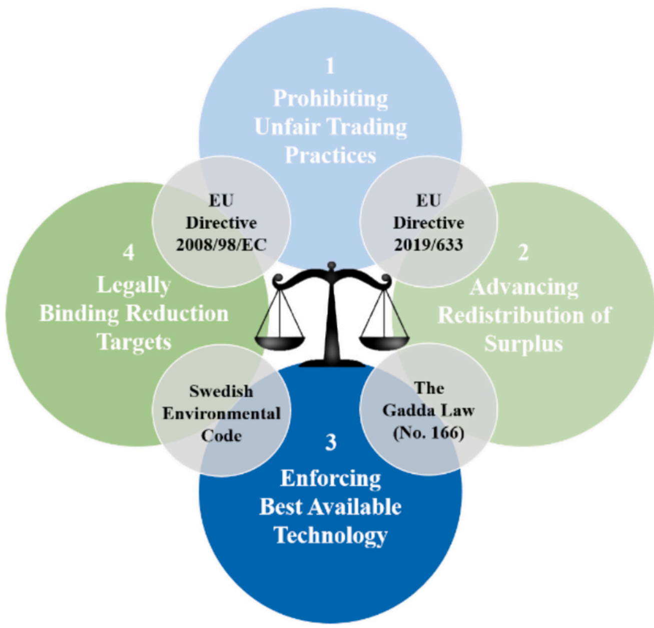

Fig. 1. Illustrating the four developed scenarios, using grey circles to indicate the modeled legislation.

waste per capita by 2030. Supporting information about the scenario design is available in Appendix A.

2.1.1. Prohibiting unfair trading practices

Aiming at mitigating unfair trading practices in business-to-business relationships within the agricultural and food supply chain, the European Parliament and the Council of the EU passed Directive 2019/633. Member states were required to implement the directive by November 2021, recognizing the power imbalances between suppliers, often leading to unfair trading practices where larger and more powerful actors could take advantage of smaller ones. Deconinck (2021) compared the current food supply chain to an hourglass, where multiple smaller suppliers provide food and resources to a few market actors, who in turn distribute to a large base of consumers. The EU directive especially supports small stakeholders, like farmers and producer organizations, by imposing regulations on the larger operators.

In Sweden, this directive was transposed into national law SFS 2021:579 (2021), which regulates Unfair Trading Practices (UTP) for entities with an annual turnover of at least two million SEK. Member states were obliged to establish a 'black list' specifying prohibited practices and a 'grey list' of conditional practices (Mannheimer Swartling, 2021). In Sweden, nine practices were placed on the black list and six on the grey list. Following the provisions of the Swedish law SFS 2021:579 (2021), TBA is considered a 'return of unsold products' and is therefore on the grey list, provided that there is a mutual agreement between suppliers and retailers. However, other countries, including Germany and France, prohibited this practice by putting it on the black list (European Commission, 2021). Although the EU Directive 2019/633 (2019) acknowledges that some practices could still be considered unfair, even when agreed upon by both parties, the directive does not provide guidance on how to address and manage this.

One of the potential drawbacks of TBAs is the risk of increased food waste due to reduced accountability among producers, who are not financially responsible for the additional food waste they generate. This would bring us back to the *Prevention Paradox* (Thyberg and Tonjes, 2016). The first scenario explores the implications of implementing the EU Directive 2019/633, by moving it from the grey list to the black. Ultimately, this would result in prohibiting take-back agreements for bread in Sweden. If TBAs were prohibited entirely, retailers would take on full responsibility for all aspects of bread management, including forecasting, ordering, assortment planning, and stock management. Thus, it is reasonable to assume that the surplus and waste management would follow the same pathways as for bread currently managed by retailers, namely, private label bread. The *Prohibiting Unfair Trading Practice* scenario was designed to capture the impact of transferring ownership of bread to retailers by prohibiting TBAs, assuming a 4.5 % loss rate for private label bread sold at retail (Brancoli et al., 2019).

2.1.2. Advancing redistribution of surplus

Although several directives already address food waste reduction, following the approval of the Waste Directive 2018/851 (amending 2008/98/CE), it is mandatory for EU member States to develop specific prevention measures and include them in their Waste Prevention Programmes. Italy and France were the first EU countries to introduce a national law targeting food waste in 2016, well before the approval of the Directive 2018/851, which proposes different regulatory and incentive-based approaches (Giordano et al., 2020; Franco and Cicatiello, 2021). However, both laws have been criticized for the lack of a monitoring strategy regarding their actual impacts.

In 2016, France enacted Law 2016–138 (2016) to address food waste (known as *the Garot law*), particularly in the retail sector (Albizzati et al., 2019). This law introduced three key measures, including enforcement of the waste hierarchy for surplus food, using economic penalties for businesses that deliberately waste still edible food, and requiring larger supermarkets to collaborate with food assistance organizations (González-Vaqué, 2017). While the law aligns with the EU's waste hierarchy, it tends to emphasize food redistribution over prevention, since retailers with sales areas larger than 400 m^2 are obliged to establish agreements for donating surplus food. The same year, Law No. 166 (2016) was passed in Italy (known as *the Gadda Law*), which enforces the food waste hierarchy similarly but places greater emphasis on encouraging donations through tax exemptions to retail via municipal incentives rather than using penalties or mandatory agreements (Giordano et al., 2020).

The second scenario explores the impact of two changes to the current bread supply chain, by firstly mirroring France's decision to prohibit UTP even under mutual agreements (European Commission, 2021), and secondly by also favoring higher levels of the food hierarchy via cooperation between larger supermarkets and food assistance organizations (González-Vaqué, 2017). Within a year of its implementation, France's law reportedly led to a 30 % increase in the quantity of food donated compared to pre-law donation levels, alongside an increase in the number of supermarkets donating surplus food (Mourad and Finn, 2019). A similar reduction potential was also reported in Italy following the enforcement of the *Gadda Law* (Szulecka et al., 2024), while one of the main food banks operating in Italy reported an increase of 97 % in food redistributed from supermarkets (Banco Alimentare, 2018). The second *Advancing Redistribution of Surplus* scenario was designed to simulate a combination of these approaches, assuming that TBAs are prohibited and that 30 % of surplus bread at retail is donated.

2.1.3. Enforcing best available technology

The Swedish Environmental Code (SFS 1998:808), enacted in 1999, is the primary environmental legislation at national level, and applies to all activities, including food businesses. This legislation aims to promote sustainable development by providing a comprehensive framework for environmental protection (Swedish Environmental Protection Agency, 2017). The EU's waste hierarchy, referenced earlier, is implemented through Ch. 2 Sec. 5 and Ch. 15 Sec. 10 of the Environmental Code SFS 1998:808 (2018), which prioritizes waste reduction, mitigating the negative impacts of waste, and promoting recycling. Chapter 15 §10 reinforces the waste hierarchy, specifically focusing on waste that has already been generated, by prioritizing preparation for reuse. In their recent study, Eriksson et al. (2023) argue that the Swedish Environmental Code theoretically suggests that wasting food is illegal in

Sweden. However, they also highlight the lack of clear definitions of what qualifies as a normal and acceptable amount of food waste. While this legislation applies to food businesses, it has not yet been enforced to specifically reduce waste in the food supply chain.

On the other hand, enforcing the best available technology to prevent, hinder or combat damage to human health and the environment, is clearly highlighted in Ch- 2 Sec. 3. This could be translated to a joint responsibility of suppliers and retailers to make sure that more produced food reach consumers, and of consumers to only demand food in parity with their actual consumption. In practical terms, this could involve enforcing data sharing between suppliers and retailers, especially since this is an identified key factor for reducing food waste (de Moraes et al., 2020; Riesenegger and Hübner, 2022). According to the rules on traceability in the food legislation (Regulation 178/2002 article 19), there is an obligation to notify other actors in the food chain if there is a suspicion that unsafe food may have been passed on, but not to prevent food waste. According to the Environmental Code, a business is obliged to provide the information to the supervisory authority that it requests (Ch. 26 Sec. 21). If there are no confidential barriers according to the secrecy legislation (SFS 2009:400), this information can be shared with others in the food supply chain. The potential benefits of sharing data in combination with surplus utilization were discussed by Bartek et al. (2025); however, their study did not consider the policy aspect. Therefore, the *Enforcing Best Available Technology* scenario was designed to simulate a stricter reinforcement of the Swedish Environmental Code, both in terms of best available technology and waste pathways. Ultimately, it was assumed that sharing data could prevent surplus bread at the supplier with 38 % and retailer with 29 %, based on the results by Nikolicic et al. (2021). The surplus that could not be prevented was assumed to follow utilization according to the waste hierarchy, with a 30 % increase in reuse via donations, maintained recovery to animal feed and ethanol production, and a smaller fraction directed toward energy recovery.

2.1.4. Legally binding reduction targets

Despite efforts toward sustainable production and consumption, legally binding global targets for reducing food loss and waste have yet to be established. However, to accelerate the progress toward achieving SDG 12.3, the European Commission put forward the legislative proposal *COD 2023/0234*, which aims to enforce legally binding food waste reduction targets. This infers an amendment of the *Directive 2008/98/EC* on food waste (Zalewska, 2024), with the aim of ensuring significant progress by 2030 and providing direction for continued improvements beyond that date. The target should be met by all member states using a step-wise approach, which should be reviewed and revised as needed to ensure the effectiveness of the legislation.

Building on the EU-wide food waste assessment conducted in 2020 as a baseline, the proposal mandates a 10 % reduction in food waste in the processing and manufacturing sectors, alongside a 30 % reduction in food waste per capita at the retail, consumption, and food service levels by 2030. The fourth *Legally Binding Reduction Targets* scenario was inspired by the proposed EU legislation, incorporating the household-level ambition of SDG 12.3 to estimate potential reductions at the EU level. In this scenario, a 50 % reduction in household bread waste was assumed, which in turn lowered the surplus requirements for retail and bakeries. With households wasting less, less production and surplus management were required, leading to reduced resource demand in both retail and bakery operations.

2.2. Life cycle assessment

The study aims to evaluate the climate benefits of enforcing four different policy changes aimed at reducing bread waste in Sweden. A consequential approach, in compliance with the ISO (ISO 14040, 2006; ISO 14044, 2006) standard, was adopted since policy changes would affect the market on a national scale. The functional unit is defined as *1 kg of bread* consumed at the household level. This includes the entire supply chain and accounts for all surplus and waste occurring from wheat cultivation to final consumption or disposal, aligning with a cradle-to-grave system boundary (Fig. 2). Retail operations, distribution logistics, and surplus management are included, while packaging and capital infrastructure (e.g., building construction) are excluded due to their relatively minor contribution to the climate impact of bread. Supporting modelling inputs for the *Baseline* scenario are provided in Appendix A, Table A1. The scenario modelling involved adjusting input flows from the baseline to reflect changes in surplus generation, redistribution, and production demand due to policy interventions. These adjustments are based on documented policy outcomes in comparable European contexts, with scenario-specific assumptions transparently presented in Appendix A, Table A2.

The multifunctionality of the scenarios, including their co-products and services, was addressed through system expansion. This approach credits the management options by considering the environmental impacts of the co-products they replace, based on market averages. The geographic scope of the study was Sweden, with the temporal scope reflecting current and near-future food management and surplus utilization practices, as feasible under existing and proposed legislation. No formal sensitivity or uncertainty analysis was conducted in this study; instead, robustness was explored through scenario analysis. SimaPro 9.5 software, coupled with the Ecoinvent 3.8 database, was used to model the scenarios, using the PEF method to assess climate impact.

3. Results

The results show that shifting from the current baseline scenario to any of the alternative scenarios led to a reduction in climate impact per kilogram of bread consumed (Table 1). The greatest positive climate effect was observed for the *Legally Binding Reduction Targets* and *Enforcing Best Available Technology* scenarios. Meanwhile, the other two scenarios provided roughly equal benefits from a climate perspective. Enforcing any of the assessed legislations was found to reduce surplus at the retail level, while enforcing the Swedish Environmental Code and legally binding reduction targets enforced by the EU could also reduce surplus at the household level. It is important to note that in the *Baseline* scenario, the surplus and wasted resources along the supply chain, from farm level to household, amounted to 0.95 kg per kg of consumed bread (wet weight basis), while all alternative scenarios resulted in less surplus along the supply chain.

The total climate impact per kilogram of bread consumed was approximately 1.9 kg CO_2e in the *Baseline* scenario and was reduced to 1.8 kg CO_2e both under *Prohibiting Unfair Trading Practice* and *Enforcing Best Available Technology*, while the climate impact was reduced to 1.6 kg CO_2e in *Advancing Redistribution of Surplus* and 1.5 kg CO_2e for the *Legally Binding Reduction Targets* scenario. The results (See Fig. 3.) further show that primary production at the farm was one of the main sources of climate impact, while system expansion was the main cause of mitigated impact.

In Fig. 4, we observe that waste management and valorisation pathways at the store level were the main factors in reducing climate impact for all scenarios. The legal changes simulated both the prevention of surplus generation and the benefits of promoting alternatives such as donations. For the *Advancing Redistribution of Surplus* scenario, we see that less ethanol can be produced from surplus bread when more is directed toward donations. However, the climate cost of substituting fewer fossil fuels turns out to be lower than the climate benefit of donating the bread, which in turn reduces the need for bread production. In the *Enforcing Best Available Technology* scenario, the benefits of preventing surplus at both the supplier and retailer levels are accompanied by additional climate benefits, such as reduced transportation demand for surplus and lower energy inputs per kilogram of consumed bread, e.g., during baking. A similar trend, with greater climate savings from legislation that enforces reduction at multiple stages of the supply

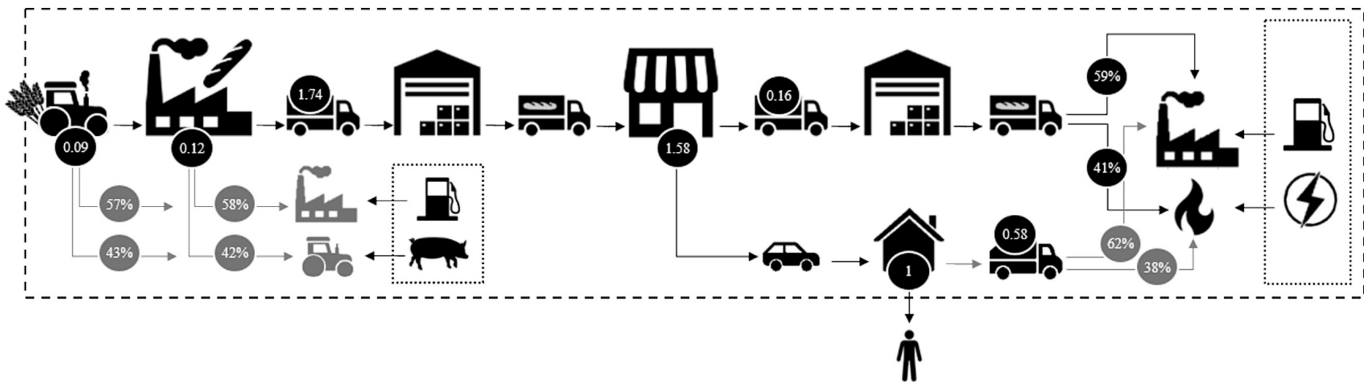

Fig. 2. System illustration of the baseline scenario for pre-packaged bread distributed under take-back agreement in Sweden. The dashed line shows the system boundary, while the dotted line indicates the substitution included via system expansion.

Table 1
Impact of shifting from the *Baseline* scenario to one of the four alternative scenarios, expressed per kg bread consumed at the household level. Positive values indicate an increase compared to baseline, while a negative value shows that the shift reduces the quantity.

		Baseline	*Prohibiting Unfair Trading Practice*	*Advancing Redistribution of Surplus*	*Enforcing Best Available Technology*	*Legally Binding Reduction Targets*
Farm (kg)	Flour	1.2	0	0	−0.01	−0.2
	Side stream	0.09	0	0	0	−0.02
	Prevention	0	0	0	0.01	0.2
	Animal feed	0.05	0	0	0	-0.01
	Anaerobic digestion	0.04	0	0	-0.01	-0.01
Bakery (kg)	Bread	1.86	0	0	−0.05	−0.36
	Surplus	0.12	0	0	−0.06	−0.07
	Prevention	0	0	0	0.06	0.07
	Donation	0.001	0	0	−0.001	-0.001
	Animal feed	0.05	0	0	−0.03	−0.03
	Ethanol production	0.02	0	0	−0.012	−0.014
	Anaerobic digestion	0.01	0	0	−0.005	−0.006
	Incineration	0.04	0	0	−0.02	-0.02
Retailer (kg)	Sold	1.74	0	0	0	−0.29
	Unsold	0.16	−0.08	−0.08	−0.05	−0.07
	Prevention	0	0.08	0.08	0.05	0.05
	Donation	0	0	0.02	0.02	0.02
	Animal feed	0	0	0	0.01	0
	Ethanol production	0.03	-0.03	0	-0.02	-0.02
	Anaerobic digestion	0.07	-0.02	-0.03	-0.03	-0.06
	Incineration	0.07	−0.04	−0.03	−0.03	−0.06
Household (kg)	Consumed	1	0	0	0	0
	Wasted	0.58	0	0	0	−0.29
	Prevention	0	0	0	0	0.29
	Anaerobic digestion	0.36	0	0	0	-0.18
	Incineration	0.22	0	0	0	−0.11
Farm to Household (kg)	Side stream	0.09	0	0	0	−0.02
	Surplus	0.12	0	0	−0.06	−0.07
	Unsold	0.16	−0.08	−0.08	−0.05	−0.07
	Waste	0.58	0	0	0	−0.29
	Total	**0.95**	**−0.08−**	**−0.08−**	**−0.11−**	**−0.45**
	Change (%)	0	8 %	8 %	12 %	−48 %
	Climate impact *	**1.9**	**−0.05−**	**−0.06−**	**−0.11−**	**−0.33**
	Change (%)	0	3 %	3 %	6 %	−18 %

* kg CO2e / kg consumed bread.

chain, was also evident for the *Legally Binding Reduction Targets* scenario. When accounting for surplus prevention at the household level, the benefit of consuming the bread instead of directing it toward anaerobic digestion or incineration became clear.

4. Discussion

While some surplus food is necessary to ensure food security, excessive levels of surplus and food waste globally undermine this goal and have significant environmental and social implications. Efforts to reduce food waste are crucial for achieving global sustainability targets.

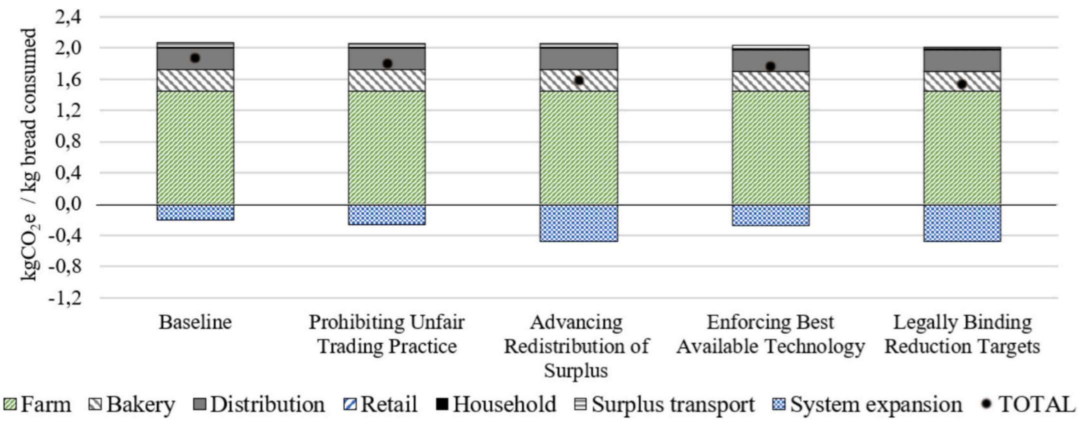

Fig. 3. Illustration of the contribution for each supply stage to climate impact assessed for both conventional and conceptual scenarios. A negative value indicates a mitigated impact, primarily due to substitution.

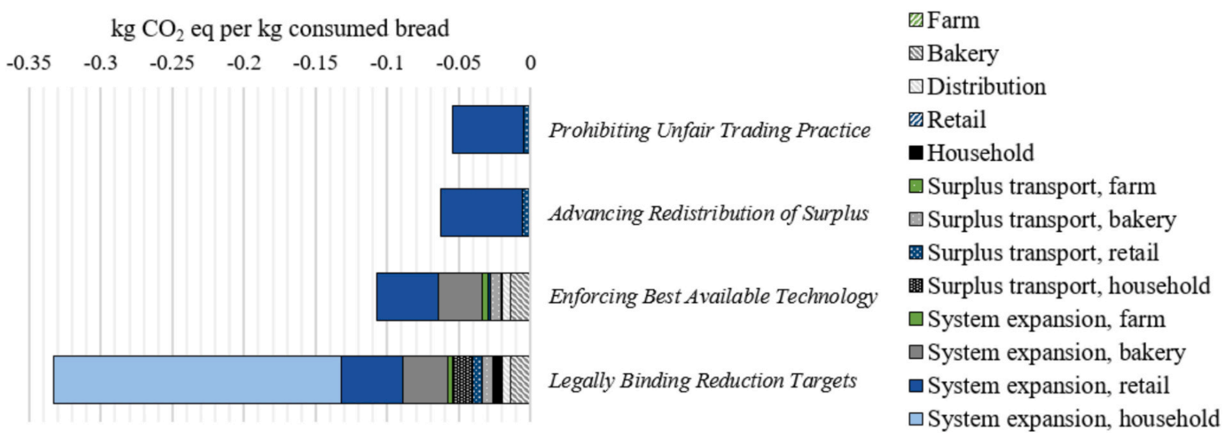

Fig. 4. Climate benefits of shifting from the conventional *Baseline* scenario to each of the alternative scenarios. Negative values indicate the potential reduction in climate impact compared to the baseline scenario.

In Sweden, addressing surplus bread specifically presents an opportunity to foster a more sustainable food system. This study explores four scenarios aimed at minimizing bread waste and enhancing surplus utilization within the bread supply chain, simulating the impact of implementing or enforcing various targeted legislation and policy measures. One of the key findings is that enforcing any of the scenarios leads to a reduction in both surplus quantities and waste, as well as a decrease in climate impact per kilogram of consumed bread. In the *Baseline* scenario, 0.95 kg of bread was lost or wasted from the farm to the household level. However, the *Prohibiting Unfair Trading Practice* and *Advancing Redistribution of Surplus* scenarios resulted in 8 % less waste and 3 % lower climate impact per kilogram of consumed bread (Table 1). The results further show that *Enforcing Best Available Technology* could reduce surplus and waste by approximately 12 %, while the *Legally Binding Reduction Targets* scenario led to nearly a 50 % reduction in waste compared to the current system.

Despite the considerable amount of food waste generated at retail levels, particularly with bread, existing policies and infrastructure often fail to prioritize prevention or reuse for human consumption. This highlights an important gap between food waste reduction policy objectives, such as the EU's emphasis on prevention and reuse, and their implementation on the ground, where surplus food is primarily treated as waste rather than a resource. These findings align with those of Mourad (2016) and Giordano et al. (2020), and can be attributed to the prevailing perception of surplus food as an environmental and economic burden, rather than a resource that could contribute to reducing food insecurity. Although this study focuses on bread, the results provide valuable insights into the effectiveness of different policy interventions, which can be applied to other food supply chains with similar waste drivers or structures, thereby offering broader implications for food waste reduction across various sectors.

Shifting the responsibility for ordering and managing bread surplus and waste from suppliers to retailers could lead to substantial reductions in waste. If TBAs were prohibited, retailers would assume the financial and logistical responsibilities for managing unsold bread, creating a strong incentive to reduce surplus through actions such as price reductions, better forecasting, or donations. However, it is important to consider the potential for burden shifting with these strategies, as they may inadvertently push food waste to the next stage of the supply chain. For example, while price reductions might reduce surplus bread at retail, they could also encourage consumers to purchase more than they can consume, leading to an increase in bread waste at the household level. This concern has been raised by Tsalis et al. (2021) and Aschemann-Witzel et al. (2021), emphasizing the need to carefully evaluate the broader impacts of different policy enforcements.

The combination of prohibiting unfair trading practices and enforcing food donations was assessed through the *Advancing Redistribution of Surplus* scenario in a Swedish context. Both this scenario and the *Prohibiting Unfair Trading Practice* scenario demonstrated similar reduction potential at the retail level (Table 1). However, the greater climate savings in the *Advancing Redistribution of Surplus* scenario were primarily driven by the higher share of surplus bread directed toward donations (Fig. 4). It is important to note, however, that even three years after the implementation of France's Law 2016–138 (2016) and the Italian Law

No. 166 (2016), Mourad and Finn (2019) reported that many charitable organizations still faced difficulties in managing donations, citing limitations such as insufficient storage capacity and irregular donation patterns. In evaluating the future of food redistribution, Papargyropoulou et al. (2022) argue that donation should not be viewed as a universally beneficial solution. They further highlight that financial, logistical, and legal challenges pose significant barriers to efficient redistribution. Addressing these barriers, as discussed by Bartezzaghi et al. (2022), is crucial when assessing policy measures, as these challenges may hinder the feasibility of otherwise promising actions. This could similarly pose a challenge in Sweden, where overcoming such barriers will be vital to avoid burden shifting. It is also important to note that for the first two scenarios, no prevention was modeled at the farm or bakery levels, as these scenarios focus on actions at the retail level. However, in practice, the implementation of these legislations could have spill-over effects on surplus prevention in the earlier stages of the supply chain. This is a typical case of 'competing solutions' for food waste prevention, as highlighted by Mourad (2016).

Under the current TBA system in Sweden, it is the suppliers, not the retailers, who handle surplus bread. Therefore, for the *Advancing Redistribution of Surplus* scenario to be effective in Sweden, either TBAs would need to be fully prohibited, or the law could be expanded to include both suppliers and retailers. It is important to acknowledge that the practical implementation of donating all surplus bread at every stage of the supply chain may not be feasible to the extent suggested by the food waste hierarchy. Furthermore, surplus food donations already contain a significant proportion of bread, sometimes leading to 'saturation' where unused bread returns to the waste stream (Sundin et al., 2022). At the same time, rising food prices and growing income disparities in Sweden have increased the demand for food donations (Berglund and Kristjansdottir, 2024), presenting an opportunity to better balance the supply and demand for surplus bread. However, the *Enforcing Best Available Technology* scenario demonstrates that, while not all surpluses can be prevented or directed to human consumption, there is still considerable potential for reduction and climate benefits associated with better utilization of surplus food, in line with the waste hierarchy. In Sweden, the Environmental Code requires that resource consumption be prevented only when environmentally justified and economically reasonable (Ch. 2 Sec. 5 and 7). Unfortunately, the lack of clear definitions of what constitutes 'reasonable' or 'justified' allows for a subjective decision-making process. Currently, around 1.3 million tons of food waste are generated annually in Sweden, with 38 % undergoing biological treatment, while only 2 % is donated (Johansson, 2021). To reduce the environmental impact of food waste, enforcing the food waste hierarchy is arguably one of the most effective approaches. This perspective is echoed by Albizzati et al. (2019), who highlight that donations and reuse as animal feed offer greater environmental benefits compared to energy recovery methods such as anaerobic digestion or incineration.

Both the *Advancing Redistribution of Surplus* scenario and the *Enforcing Best Available Technology* scenario demonstrate the reduction potential for surplus bread, and the climate savings linked to this, when enforced via legislation. Important to note is that economic incentives are often important drivers for food donations, as the donation process incurs additional costs for storage and logistics that are often avoided for pathways toward energy recovery (Franco and Cicatiello, 2021; Lohnes, 2021). Therefore, a combination of economic disincentives, such as increased waste management costs, and incentives, such as tax benefits for donations, could be effective measures relevant for all assessed scenarios. However, it is crucial to be mindful of the potential risk of shifting food waste to charities and households, as already highlighted (Mourad and Finn, 2019).

The *Enforcing Best Available Technology* scenario also demonstrated the benefits of enhancing collaboration among stakeholders in the supply chain without requiring major changes to the existing TBA system. With increasing digitalization, improved forecasting, and more detailed inventory management, along with advanced point-of-sale systems, there are opportunities to enforce shared data exchange between suppliers and retailers. Since this can be considered a market-based approach, even though enforced via the Swedish Environmental Code, it may be more widely accepted by stakeholders compared to purely regulatory measures. However, it is also important to note that while Swedish authorities have the right to request data from companies, confidentiality provisions in the law on public rights and confidentiality may make it difficult for authorities to share this data. This challenge underscores the need for a common incentive among stakeholders to drive this change, making it more profitable for them to engage voluntarily rather than relying solely on enforcement. On assessing a similar issue, Eriksson et al. (2023) stressed that although food waste is theoretically illegal under Swedish law, enforcement is substantially lacking. This emphasizes the need for active enforcement, as simply declaring food waste illegal or deciding to enforce best available technology is insufficient. Real change requires regulations to be implemented and monitored to drive compliance and impact.

On exploring risk factors of food loss and waste, Realpe et al. (2024) highlighted the influence of retailer-supplier relationships on surplus food and emphasized the need for cooperation throughout the supply chain to address and reduce its effects. For instance, the impact of allowing retailers to offer bread at reduced prices, particularly as it approaches its best-before date, was simulated in the *Prohibiting Unfair Trading Practice* scenario, which successfully reduced both the surplus generated and the associated climate impact. Corsini et al. (2023) also discussed the role of digital technologies in facilitating efforts to promote products nearing their expiration date by offering them at discounted prices. There is, however, an ongoing debate about the effects of price reductions on food waste at the household level. Some authors argue that pricing mechanisms such as discounts and multi-item offers can encourage over-purchasing, leading to increased food waste (Hegnsholt et al., 2020). On the other hand, Tsalis et al. (2024) suggested that households purchasing food on discount may actually waste less, challenging the assumption that discounts inherently lead to waste. This complexity underscores the importance of carefully evaluating pricing strategies and their broader implications for food waste. By coupling enforced legislation with additional incentives to inform, guide, and support actors along the supply chain, ranging from farmers to consumers, this risk could be mitigated (Cicatiello et al., 2020; Simões et al., 2022; Tsalis et al., 2024). Another risk of addressing overproduction (a market externality) by selling underpriced products or increasing donations lies in the implications of social justice. This approach creates a stable dual market system, where one group of consumers lacks agency and is subjected to the visible markers of poverty. The separation of distribution channels for poor and non-poor consumers, the limited consumer choice available to disadvantaged groups, and the visible differences in the quality of goods accessible to poor versus non-poor consumers are institutional factors that can lead to shame among consumers, particularly in societies where the level of socially expected consumption is high (Nadai and Böhme, 2024).

The results for the *Legally Binding Reduction Targets* scenario indicate that, although the previous scenarios successfully reduced both the generation of surplus and the climate impact per kg of consumed bread, legislation or policy measures aimed at reducing food waste at the household level would likely result in even greater benefits (Fig. 3). While the *Legally Binding Reduction Targets* scenario highlights the potential for substantial environmental gains, it is important to acknowledge its limitations. This scenario assumes that setting mandatory targets will effectively reduce household food waste by 50 % and lead to proportional decreases in upstream production and associated emissions. However, the success of such targets in practice is far from guaranteed. As seen in climate policy, legally binding targets often face challenges related to enforcement, political incentives, public acceptance, and the complexity of behaviour change. In the context of food waste, these challenges may be exacerbated by the private and decentralized nature of household decisions. Without clear implementation mechanisms, such as economic incentives, awareness campaigns, or improved date labelling, targets risk remaining symbolic rather than truly transformative. Therefore, while the scenario provides an optimistic view of potential outcomes, its assumptions should be interpreted with caution. In their evaluation, van Zanten and Putintseva (2025) found that Sweden was among the 21 % of 170 countries with policies supportive of the SDG, but only to a moderate degree. Future research should explore how such food waste reduction targets and fulfillment of SGDs might realistically be achieved, alongside what combination of regulatory, informational, and behavioural interventions is most effective in driving durable change. This is especially important since, as also voiced by Bogers et al. (2022), increased SDG use does not necessarily imply higher policy integration. Despite this, the results for this scenario align with the conclusions of Priefer et al. (2016), who emphasized that the most relevant leverage points for action span all stages of the supply chain. Given the considerable annual consumption of bread and bakery products in Sweden, there could be considerable climate gains through the enforcement of any of the modeled legislations. However, it is important to consider the potential disconnection between legal enforcement and practical outcome for all assessed scenarios, since factors such as vague mandates or a preference for easily implementable solutions over systemic change could reduce, or even hinder, the potential climate benefits.

The *Baseline* scenario resulted in a climate impact of 1.9 kg CO_2e per kg consumed bread when accounting for losses and waste during all stages of the supply chain. The best performing *Legally Binding Reduction Targets* scenario was found to have an 18 % climate reduction potential (Table 1), which translates to an impact of roughly 1.5 kg CO_2e per kg consumed bread. This is slightly higher, but still in the same order of magnitude as previous studies. When assessing the impact of bread using a cradle-to-gate approach, Rafiee et al. (2024) and Ingrao et al. (2018) found an average climate impact of 0.66 kg CO_2e and 0.5 kg CO_2e per kg bread, respectively. Using a similar cradle-to-grave approach as the present study, Espinoza-Orias et al. (2011) found that 800 g of consumed bread inferred roughly 1.2 kg CO_2e. However, their study assumed a fixed 10 % waste of bread along the supply chain, which is lower compared to the Swedish baseline (Fig. 1). On accounting for the different waste rates along the bread supply in Norway, Svanes et al. (2019) found a climate impact of 0.99 kg CO_2e per kg bread. The present results can be considered broadly in line with previous studies, reinforcing the reliability of our estimates while highlighting the added value of including detailed, stage-specific waste data across the full bread supply chain.

The choice of system boundary and functional unit contributes to the higher climate impact observed in this study, as it includes more stages of the supply chain. By adopting a cradle-to-grave system boundary, this study accounts for waste at all stages, including at the household level. As a result, the input, such as wheat, is calculated to cover both the bread that is consumed and the bread that is discarded. This comprehensive approach likely explains the higher climate impact per kg of bread compared to previous studies. The findings also reveal that surplus bread represents a significant climate burden due to inefficiencies throughout the supply chain, particularly in wheat production. These results align with previous studies that identify preventing wheat production as a key strategy for reducing the environmental footprint of bread (Espinoza-Orias et al., 2011; Brancoli et al., 2019; Bartek et al., 2025). Svanes et al. (2019) further emphasized that waste generated at the household level is a critical hotspot for climate impact, while Brancoli et al. (2020) noted that source reduction in wheat production is another important factor for minimizing environmental effects. Furthermore, this study did not incorporate rebound effects, as the focus was on modelling the direct impacts of policy measures. Although including rebound effects would add complexity to the analysis, they are essential to consider in future research to fully evaluate the broader implications of food waste reduction policies (Hegwood et al., 2023). The present results underscore the need for broader policy frameworks that address food waste across the entire supply chain, from farm to household.

Although the present study quantifies the climate benefits of specific legislative measures in the Swedish bread sector, several avenues would remain for further investigation. Firstly, future work could explore the combined environmental, social, and economic impacts of such policies, particularly their effects on food insecurity and market dynamics. Secondly, applying this modelling framework to other high-waste, perishable food sectors, such as dairy or fresh produce, would test the transferability of results. Thirdly, longitudinal studies tracking real-world policy implementation could capture behavioural responses, compliance levels, and unintended consequences over time. Finally, cross-country comparative analyses could identify contextual factors that influence policy effectiveness, enabling the design of legislation tailored to diverse governance and market environments.

While the Swedish bread market has specific features, such as the use of take-back agreements, the underlying mechanisms of surplus generation, retailer incentives, and short shelf life are shared with many perishable food categories across Europe and beyond. Similar legal instruments, such as the French and Italian laws on food donation, demonstrate that regulatory interventions can be successfully scaled and adapted across national contexts, despite initial concerns about cost, logistics, or food safety. However, some countries have reported challenges such as a lack of cold chain infrastructure or increased burden on charities, which highlight the importance of tailored implementation and stakeholder engagement. Ethical considerations should also be accounted for, such as ensuring that food redistribution scenarios align with food safety regulations to prevent health risks, particularly when surplus bread is donated. Practical barriers, such as retailer willingness and available infrastructure for safe handling and tracking of redistributed food, must also be addressed to ensure both effectiveness and public trust. Conversely, overly strict food donation regulations in some countries have raised concerns about food safety and logistical feasibility, highlighting the need for flexible, well-coordinated systems. This study positions its scenario-based approach within these global efforts by using life cycle modelling to assess the climate impact of feasible interventions, offering a framework that can be adapted to other perishable food sectors and national contexts with appropriate adjustments. Although this study provides valuable insights into the potential climate benefits of legislative interventions, the conclusions should be interpreted with caution due to the specific characteristics of the Swedish bread supply chain and assumptions made. Real-world implementation may face challenges such as stakeholder compliance, increased logistical complexity, enforcement costs, and unintended consequences like overburdened donation systems or shifts in waste to other stages of the chain. Mueller (2020) also concluded that even well-designed policy instruments must contend with the limitations of complex systems, and expectations for policy outcomes should be tempered to reflect these systemic constraints. Given the results and insights of the present work, we emphasize the importance of reflecting on the broader implications of using legislative tools to reduce food waste. Furthermore, as also voiced by (Pasarín and Viinikainen, 2022), regulatory interventions to reduce food loss and waste must be designed within a comprehensive agrifood system perspective, recognizing the interconnected actors and potential trade-offs, while ensuring that measures are context-specific to national and local realities. But most importantly, while legislative interventions may have limitations, the risks of inaction are far greater since doing nothing allows avoidable waste and its environmental impacts to persist unchecked.

5. Conclusions

This study addresses a critical research gap by quantifying the climate benefits of specific legislative instruments aimed at reducing surplus bread waste, an area previously underexplored in food waste policy research. By modelling the implementation of four realistic policy scenarios, the study demonstrates that combining binding regulations with market-based incentives, such as prohibiting unfair trading practices and encouraging food donations, can reduce surplus and associated climate impact by up to 18 %. Among the scenarios tested, binding regulations that prohibit unfair trading practices, when paired with incentives for food donation, emerged as the most effective in balancing waste prevention and redistribution. This suggests that legislation can act not only as a compliance tool but as an enabler of systemic change, particularly when aligned with the food waste hierarchy and integrated into broader sustainability strategies.

For policymakers, these findings highlight the importance of moving beyond voluntary agreements toward enforceable measures that address structural inefficiencies in supply chains. For practitioners, they provide evidence-based guidance on prioritizing interventions that couple prevention with redistribution, ensuring that surplus food retains its highest value. While the Swedish bread sector served as the case study, the mechanisms identified are applicable to other perishable goods and to markets with similar supplier–retailer dynamics. The study also underscores practical challenges that must be addressed to translate legislative intent into outcomes, including retailer–supplier coordination, logistical infrastructure for donations, and monitoring for compliance. Future policy design should therefore combine robust enforcement mechanisms with stakeholder support to avoid unintended consequences. By making explicit the pathways through which law can reduce surplus and emissions, these findings offer a transferable framework for designing climate-smart food waste legislation that delivers both environmental and social benefits. In doing so, it advances our understanding of how law can serve as a lever for systemic change in building more sustainable food systems.

Declaration of competing interest

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

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Appendix A. Appendix

The *Baseline* scenario reflects the current average Swedish bread supply chain, including conventional production practices, ingredient inputs, transportation distances, energy use, and food losses at each stage, from primary production to household consumption. All alternative scenarios were modeled using this baseline as a reference, with calculated adjustments to input flows to simulate the systemic shifts assumed under each scenario. These adjustments draw on empirical data, literature, and expert judgment. Transportation inputs were derived from Weber et al. (2023), providing average distances, transport modes, and energy use specific to Swedish food supply chains. Ingredient and energy inputs for bakery production were based on Bartek et al. (2025), who provide quantification and performance benchmarks for Swedish bakeries. Food losses and waste along the supply chain were modeled using data from, e.g., Brancoli (2021) and Hildersten et al. (2025), complemented by the latest estimates for national statistics (Swedish board of Agriculture, 2023). Each scenario models a specific intervention aimed at reducing surplus bread and food waste, with assumptions informed by literature and real-world policy developments.

1. **Prohibiting Unfair Trading Practices:** This scenario explores the implications of fully implementing the EU Directive 2019/633 in Sweden by prohibiting take-back agreements (TBAs) for bread, shifting the practice from the 'grey list' to the 'black list'. In this case, retailers would take full responsibility for forecasting, ordering, and managing surplus, as is currently the case for private label bread. Accordingly, this scenario assumes a 4.5 % retail-level loss rate, based on data for private label bread, replacing higher loss rates typically associated with producer-managed branded bread under TBAs.
2. **Advancing Redistribution of Surplus:** This scenario models the effects of two concurrent changes: (1) full prohibition of TBAs, even under mutual agreement, and (2) a systematic scale-up of surplus bread donation to food assistance organizations. Drawing on post-implementation results from France's food waste legislation and Italy's Gadda Law, this scenario assumes that 30 % of surplus bread at retail is redistributed for human consumption. This results in a corresponding reduction in bread waste treatment and a substitution effect in food production elsewhere, reflecting the environmental benefits of moving surplus bread higher up the food waste hierarchy.
3. **Enforcing Best Available Technology:** This scenario simulates the deployment of advanced process control and production planning technologies in industrial bakeries. These can include predictive demand forecasting systems, automated portioning, real-time baking and packing optimization, and tighter quality control measures. Such technologies are assumed to reduce overproduction and in-process waste by 30 %.
4. **Legally Binding Reduction Targets:** This scenario assumes the implementation of national-level policy targets mandating a 50 % reduction in household food waste, consistent with the goals of SDG 12.3. The reduced household demand is assumed to propagate upstream, leading to proportionate reductions in production, transport, and ingredient use across the supply chain.

All scenarios apply the estimated changes as linear reductions in relevant input flows, ensuring comparability across scenarios. While this modelling approach simplifies real-world feedback loops and behavioural dynamics, it provides a transparent and replicable framework for assessing the relative climate impact of different food waste interventions. The following section presents the inventory data used to model the baseline scenario, expressed per kg of consumed bread at the household level. All inputs are disclosed in Table A1, using Ecoinvent datasets accessed via SimaPro 9 in modelling, which were used to represent each relevant process across the supply chain.

Table A1
Inventory data for the baseline scenario, showing both inputs and outputs for each stage.

Process stage			Amount	Unit
Farm	Input	Wheat flour	1.04	kg
		Rye flour	0.26	kg
		Transport, tractor	40	km
	Output	Flour	1.21	kg
		Side stream	0.09	kg
		Animal feed	0.05	kg
		Anaerobic digestion (AD)	0.04	kg
		Transport, feed	352	km
		Transport, AD	13	km
Bakery	Input	Flour	–	–
		Salt	0.06	kg
		Raising agent	0.18	kg
		Water	0.69	kg
		Electricity	0.65	kWh
		Heat	0.01	kWh
		Transport, lorry	40	km
	Output	Bread	1.74	kg
		Surplus	0.12	kg
		Donation	0.001	kg
		Animal feed	0.05	kg
		Ethanol	0.02	kg
		Anaerobic digestion	0.01	kg
		Incineration (IN)	0.04	kg
		Transport, donation	5	km
		Transport, feed	352	km
		Transport, ethanol	291	km
		Transport, AD	13	km
		Transport, IN	13	km
Distribution	Input	Electricity	0.01	kWh
		Heat	0.002	kWh
		Transport, train	177	km
		Transport, train $_{Frozen}$	153	km
		Transport, lorry	278	km
		Transport, lorry $_{Frozen}$	3	km
Retailer	Input	Electricity	0.04	kWh
		Heat	0.02	kWh
	Output	Sold bread	1.58	kg
		Unsold bread	0.16	kg
		Ethanol	0.03	kg
		Anaerobic digestion	0.07	kg
		Incineration	0.07	kg
		Transport, ethanol	291	km
		Transport, AD	13	km
		Transport, IN	13	km
Household	Input	Bread	–	–
		Transport, car	40	km
	Output	Consumed	1	kg
		Wasted	0.58	kg
		Anaerobic digestion	0.34	kg
		Incineration	0.24	kg
		Transport, AD	40	km
		Transport, IN	40	km

Table A2 provides an overview of the underlying calculations used to quantify input adjustments for each scenario relative to the baseline. These calculations include the percentage reductions in losses, production volumes, and associated inputs (e.g., ingredients, energy, transport) applied at each relevant stage of the supply chain. Each scenario's assumed intervention, described in the previous section, was translated into estimated changes in mass flows per kg of consumed bread. These values formed the basis for the modified life cycle inventory, using the *Baseline* in Table A1, for each scenario.

Table A2
Mass balance calculations for each scenario, showing inputs and outputs for each stage per kg of consumed bread.

	Bakery		➔	Retail		➔	Household		
	Input [kg]	1.86	100 %	Input [kg]	1.74	100 %	Input [kg]	1.58	100 %
	Output [kg]	1.74	94 %	Output [kg]	1.58	91 %	Output [kg]	1	63 %
base case	Surplus [kg]	0.12	6 %	Surplus [kg]	0.16	9 %	Waste [kg]	0.58	37 %
	Prevention	0	0 %	Prevention	0	0 %	Prevention	0	0 %
	Donation	0.001	1 %	Donation	0	0 %	Donation	0	0 %
	Feed	0.05	42 %	Feed	0	0 %	Feed	0	0 %
	Ethanol	0.02	19 %	Ethanol	0.03	18 %	Ethanol	0	0 %
	AD	0.01	8 %	AD	0.07	41 %	AD	0.36	62 %
	Incineration	0.04	30 %	Incineration	0.07	41 %	Incineration	0.22	38 %

(continued on next page)

Table A2 (*continued*)

	Bakery		➔	**Retail**		➔	**Household**		
scenario 1	Input [kg]	1.86	100 %	Input [kg]	1.74	100 %	Input [kg]	1.58	100 %
	Output [kg]	1.74	94 %	Output [kg]	1.58	95.5 %	Output [kg]	1	63 %
	Surplus [kg]	0.12	6 %	Surplus [kg]	0.078	4.5 %	Waste [kg]	0.58	37 %
	Prevention	0	0 %	Prevention	0.08	51.3 %	Prevention	0	0 %
	Donation	0.001	1 %	Donation	0	0 %	Donation	0	0 %
	Feed	0.05	42 %	Feed	0	0 %	Feed	0	0 %
	Ethanol	0.02	19 %	Ethanol	0	0 %	Ethanol	0	0 %
	AD	0.01	8 %	AD	0.05	30.2 %	AD	0.36	62 %
	Incineration	0.04	30 %	Incineration	0.03	18.5 %	Incineration	0.22	38 %
	Bakery		➔	**Retail**		➔	**Household**		
scenario 2	Input [kg]	1.86	100 %	Input [kg]	1.74	100 %	Input [kg]	1.58	100 %
	Output [kg]	1.74	94 %	Output [kg]	1.58	91 %	Output [kg]	1	63 %
	Surplus [kg]	0.12	6 %	Surplus [kg]	0.08	4.5 %	Waste [kg]	0.58	37 %
	Prevention	0	0 %	Prevention	0.08	51 %	Prevention	0	0 %
	Donation	0.001	1 %	Donation	0.02	15 %	Donation	0	0 %
	Feed	0.05	42 %	Feed	0	0 %	Feed	0	0 %
	Ethanol	0.02	19 %	Ethanol	0	0 %	Ethanol	0	0 %
	AD	0.01	8 %	AD	0.03	17 %	AD	0.36	62 %
	Incineration	0.04	30 %	Incineration	0.03	17 %	Incineration	0.22	38 %
	Bakery		➔	**Retail**		➔	**Household**		
scenario 3	Input [kg]	1.75	100 %	Input [kg]	1.69	100 %	Input [kg]	1.58	100 %
	Output [kg]	1.69	97 %	Output [kg]	1.58	94 %	Output [kg]	1	63 %
	Surplus [kg]	0.059	3.4 %	Surplus [kg]	0.11	6.4 %	Waste [kg]	0.58	37 %
	Prevention	0.06	51 %	Prevention	0.05	33 %	Prevention	0	0 %
	Donation	0.001	0.5 %	Donation	0.02	15 %	Donation	0	0 %
	Feed	0.02	20.7 %	Feed	0.01	6 %	Feed	0	0 %
	Ethanol	0.011	9.3 %	Ethanol	0.01	6 %	Ethanol	0	0 %
	AD	0.005	3.9 %	AD	0.03	20 %	AD	0.36	62 %
	Incineration	0.02	14.8 %	Incineration	0.03	20 %	Incineration	0.22	38 %
	Bakery		➔	**Retail**		➔	**Household**		
	Input [kg]	1.43	100 %	Input [kg]	1.38	100 %	Input [kg]	1.29	100 %
scenario 4	Output [kg]	1.38	97 %	Output [kg]	1.29	94 %	Output [kg]	1	78 %
	Surplus [kg]	0.049	3,4 %	Surplus [kg]	0.09	6.4 %	Waste [kg]	0.29	22 %
	Prevention	0.07	59 %	Prevention	0.05	37 %	Prevention	0	0 %
	Donation	0.001	0.5 %	Donation	0.02	14 %	Donation	0	0 %
	Feed	0.02	17.2 %	Feed	0	0 %	Feed	0	0 %
	Ethanol	0.009	7.7 %	Ethanol	0.01	7 %	Ethanol	0	0 %
	AD	0.004	3.3 %	AD	0.003	2 %	AD	0.18	62 %
	Incineration	0.01	12.3 %	Incineration	0.003	2 %	Incineration	0.11	38 %

Data availability

Data will be made available on request.

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