Global Dietary Transition and Food Loss and Waste Reduction: Impacts and Interactions

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Abstract

Reducing global food loss and waste (FLW) is a central pillar in the transition towards a healthier and more sustainable diet. Using a global economic model that traces FLW across supply chains, we investigate how dietary shifts interact with FLW reduction targets by 2050. Dietary shifts alone are insufficient for bending the curve of FLW generation as growing population and incomes increase total FLW volumes, particularly in low-income countries. Globally, FLW increase for oilseeds and fish, while in high-income countries, higher demand for fresh plant-based foods contributes to greater losses during the production stage. The increased exports of plant-based products from lower-income to higher-income regions exacerbate farm-level FLW in lower-income regions, affecting food security. Coupling dietary transitions with targeted FLW reductions successfully controls spillovers on a global scale. A combined strategy reduces global FLW by 63.2% in 2050, eliminating commodity-specific and stage-specific spillovers with major benefits in sub-Saharan Africa, where nutritional availability increases by 365 calories per-capita-per-day by 2050. Transitioning towards a healthier and more sustainable diet at a global level requires therefore, a targeted set of policies that incentivise FLW reduction or reusing strategies for effectively preserving the nutritional and environmental benefits of global dietary shifts by 2050.

Summary

Background

Food loss and waste (FLW) undermine the resilience and sustainability of global food systems, jeopardizing progress toward the Sustainable Development Goals (SDGs). Adopting healthier and more sustainable diets could help reduce global FLW, but the potential trade-offs on FLW trends and interactions with stand-alone FLW reduction policies are largely unexplored. This study investigates the effects of reducing FLW within the context of a global dietary transition by 2050, shedding light on the synergies and trade-offs between two critical policy areas for the food systems of the future.

Methods

We bridge the economic and technical modelling of FLW by adding consistent tracing of FLW in physical quantities along global FSC within a global computable general equilibrium (CGE) modelling framework which captures behavioural responses of economic actors along food and non-food supply chains. We build upon the Global Trade Analysis Project (GTAP) Data Base, incorporating data extensions for energy, nutritional accounts, and food loss and waste flows along stages of global supply chains. First, we investigate the impact of halving global FLW through technological developments by 2050, in line with the SDG12.3 target. Next, we analyse the impact of transitioning to healthier and more sustainable diets by 2050, promoting a global dietary transition through behavioural changes. We explore this dietary transition both with and without the goal of halving global FLW, highlighting how FLW targets interact with dietary changes on a global scale. Our scenario results illustrate how the magnitude, composition, location, and reuse potential of FLW may evolve under different scenarios compared to the business-as-usual dietary developments.

Findings

Food loss and waste (FLW) along global supply chains are expected to sharply rise by 52.0% (1116 million tons) by 2050 under the continuation of historical trends. Diet shifts alone are insufficient to curb the rise in FLW as demographic trends and growing incomes drive the total volume of lost and discarded food, with 2050 levels exceeding those of 2014 by 27.7%. Regional spillover effects of healthier diets exacerbate FLW trends, especially in Sub-Saharan Africa (SSA) and Middle-East and North Africa (MENA). In SSA, rapid population growth and increased per-capita GDP drive FLW when dietary changes are implemented (+132.2% from 2014 to 2050) and when stand-alone FLW reduction targets are applied (+62.5% from 2014 to 2050). Globally, dietary shifts drive FLW for oilseeds and fish, surpassing baseline levels by 2050. Further spillovers emerge in high-income countries where demand for fresh plant-based foods drives losses at production stages. Finally, global trade amplifies FLW in exporting regions as growing exports of plant-based products from SSA and Latin America to Europe, the U.S., and India increase farm-level FLW. Coupling dietary transitions with targeted FLW reduction policies in line with SDG12.3 successfully controls spillover effects on a global scale. A combined strategy can reduce global FLW by 63.2%, eliminating commodity-specific and stage-specific spillovers, enhancing the effectiveness of dietary changes. Particular benefits can be achieved in SSA where nutritional availability can increase up to 365 calories per-capita-per-day by 2050.

Interpretation

Policies promoting healthier diets must consider spillover effects on FLW. As shifts in production, consumption, and trade alter the magnitude, location, and composition of FLW, monitoring these changes is crucial to determining the priority areas for the FLW reduction or reuse interventions, especially in low-income regions. While dietary shifts can improve nutrition, new technologies and market-based approaches to reuse FLW—whether linked to domestic consumption or trade—can create economic opportunities and environmental benefits. To maximize these benefits,

FLW reduction should be central to discussions on dietary transition policies, as spillover effects risk undermining the positive outcomes of a global dietary shift.

Funding

No specific funding was provided for this study.

Research in context

Evidence before this study

The relationship between global dietary transitions and food loss and waste (FLW) has been explored in prior studies (Helander et al., 2021; van Selm et al., 2022; Gatto et al., 2023). However, these studies often overlook the transition pathways that lead to adopting healthy diets globally, failing to account for feedback mechanisms and rebound effects when price shifts occur due to dietary changes. Most research additionally lacks a temporal dimension, providing static analyses without insight into future trends (e.g. Helander et al., 2021) or explores only a partial dietary transition without fully achieving the EAT-Lancet dietary recommendations (e.g. Gatto et al., 2023). Addressing these limitations, our approach combines technical and economic modelling of biomass to endogenously represent market-based policies enhancing dietary shifts, further analysing impacts on FLW flows across global food supply chains towards 2050. At the core of our methodology lies the GTAP database (Aguiar et al., 2019), a widely used global database, combined with previously published extensions (GTAP-Power, Chepeliev, 2020; GTAP-FBS, Chepeliev et at., 2022) to ensure an overall consistency of our data with other databases such as the FAO Food Balance Sheets. For FLW estimates, we use data from Gatto and Chepeliev (2024). Our economic model is the dynamic Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model (van der Mensbrugghe, 2024), which has been widely applied in the fields of nutrition and sustainability (Nelson et al., 2014; Valin et al., 2014; Chepeliev et al., 2023).

Added value of this study

Our analysis advances the understanding of the interaction between dietary transitions and FLW generation by 2050. From a modelling perspective a key innovation is the tracing of physical FLW flows across supply chain stages within a global value-based economic framework, relying on an up-to date FLW database calibrated with country-specific net intakes. Our modelling framework allows for several novelties. We investigate the intersection of dietary transitions and FLW reduction targets, identifying global synergies and spillovers in a dynamic setting where production, trade and food consumption react to changing prices over time. This important feature was often overlooked in previous studies (e.g. Willett et al., 2019; Springmann et al., 2021), where static models were adopted. In this, the use of a global general equilibrium model is crucial for understanding the interactions between food and non-food sectors, capturing the competition for biomass between these sectors, which influences food production and, consequently, shapes FLW patterns. Through our economy-wide framework, we quantify FLW linked to processed foods and food services, enabling the tracing of FLW for farm to fork and across countries, a feature missing in previous investigations mainly focusing on primary agrifood sectors. Finally, our enhanced FLW tracing framework consents to investigate the impacts of diets on evolving FLW trends across countries, commodities, and supply chain stages, understanding commodity-specific or stage-specific impacts, which is the key for devising targeted policies for improving the effectiveness of dietary changes.

Implication of all the available evidence

Our results indicate that global dietary transitions must address the spillover effects on food loss and waste (FLW) generation, integrating direct interventions to reduce or reuse lost and discarded foods along global supply chains. In lower-income regions such as Sub-Saharan Africa and Middle-East & North Africa, dietary shifts need to be coupled with technological innovations to minimize the rising FLW levels, particularly at production level, in order to achieve significant benefits for nutritional security. Globally, as spillovers on FLW arise for fish and oil seeds, dietary shifts should be supported by market-based incentives that encourage the reuse of oilcakes and fishmeal as production input in the form of feed or fertiliser, maximizing the use of discarded products towards more sustainable production systems. Finally, policies in high-income countries should promote the reuse of rising plant-based agricultural losses to prevent environmental spillage and provide a more sustainable input for agrifood production.

Background

Food loss and waste (FLW) generated along global food supply chains (FSC) currently undermine the resilience and sustainability of food systems (Guo et al., 2023), endangering the environment while threatening our path toward the Sustainable Development Goals (SDGs) (U.N., 2019). Promoting a global dietary transition towards a healthier and more sustainable diet with complementary reductions in FLW is a central challenge to achieving the SDGs. While available studies largely focus on synergies between nutritional (SDG2) and environmental (SDG13) challenges (for example Davis et al., 2016; Springmann et al., 2016, 2018), potential trade-offs with FLW targets (SDG12.3) are often overlooked, and the interaction between sustainable diets and FLW generation remains largely unexplored (Helander et al., 2021).

A healthier and more sustainable plant-based diet (Willett et al., 2019) requires a rise in consumption of plant-based food which are often linked to the highest FLW levels (Delgado et al., 2021). The increased availability of high-quality plant-based FLW along global FSC (Gatto et al., 2023) could promote its reuse in regions where FLW-based inputs can enhance market competitiveness. However, the additional increase of imports of plant-based foods in high-income regions risks causing greater farm-level losses in exporting middle- and low-income regions (Gatto & Chepeliev, 2024), where FLW reuse is less feasible or competitive. Such spillover effects risk undermining the effectiveness of FLW reduction strategies, parallelly reducing the benefits of a more sustainable diet.

Assessing the trade-offs between global dietary changes and FLW reductions requires quantifying lost or discarded food along FSC while simultaneously addressing changes in consumer and producer behaviour across the economic system. While recent developments in global measurements of FLW (FAO, 2019; OECD 2021; Gatto & Chepeliev, 2024) have contributed to the challenge of a consistent global FLW quantification, the missing analysis of FLW trends when production, consumption, and global trade shift due to a higher demand for healthier and more sustainable foods generates several knowledge gaps.

Attempts to quantify FLW within dietary transitions often rely on detailed FLW data but provide a limited representation of global FSC, focusing on selected commodities or countries (Helander et al., 2021). Available studies on FLW developments within dietary transitions (see for example Conrad et al., 2018; van Selm et al., 2022) frequently overlook the dynamics of the global economic system, failing to account for changes in agents' behaviour when dietary shifts occur (Chaboud & Daviron, 2017). Moreover, existing global economic analyses often rely on partial equilibrium (PE) models (Lopez Barrera & Hertel, 2020; Springmann et al., 2018, 2021), which restrict their focus to primary agricultural sectors and ignore changes in the processing and service parts of FSC, as well as interactions with non-food sectors. Finally, while much attention is often given to FLW variations across food commodities and regions, there is limited research on how FLW location shifts across different stages of the supply chain when consumption moves towards healthier and more sustainable diets.

Building on these limitations, Gatto et al. (2023) adopt a global general equilibrium (GE) model to quantify the impact of transitioning toward the EAT-Lancet diet (Willett et al., 2019) on global FLW. This approach provides a multicountry and multi-sectoral market-based analysis of lost and discarded foods along global FSC when diets change. However, the study models only a partial transition towards a global sustainable diet, yielding relatively moderate effects compared to a full transition where dietary targets are fully met.

In this study we consolidate the data and methodological advances of the earlier literature and investigate the impact of a global transition towards a healthier and more sustainable diet on the generation of FLW across global supply chains. We bridge the economic and technical modelling of FLW by adding consistent tracing of FLW in physical quantities along global FSC within the GE modelling framework capturing behavioural responses of economic actors along food and non-food supply chains. Our analysis relies on the recent update of the Shared Socioeconomic Pathway (SSP) Projections (IIASA, 2024), thus accounting for the revised future macroeconomic and demographic trends across countries. First, we investigate the impact of halving global FLW by 2050, in line with the SDG12.3 target. Next, we analyse the impact of transitioning to healthier and more sustainable diets by 2050. Specifically, we explore this dietary transition both with and without the goal of halving global FLW, highlighting how FLW targets interact with dietary changes on a global scale. Our scenario results illustrate how the magnitude, composition, location, and reuse potential of FLW may evolve under different scenarios compared to the business-as-usual dietary developments.

Methods

Socio-economic, nutritional, and FLW data

The core data input for the development of the modelling framework is a Global Trade Analysis Project (GTAP) Power Data Base (Aguiar et al., 2019; Chepeliev, 2020a). GTAP is a global dataset that describes bilateral trade patterns, production, consumption and intermediate use of commodities and services in the countries/regions around the world. The 10th release of the GTAP Data Base, utilized in this study, has multiple reference years, with 2014 being the most recent one, covers 141 regions and disaggregates an economy in each region into 76 activities. Agricultural and food activities in the database are represented by 20 sectors, including 12 primary agricultural sectors and 8 food-processing sectors (Aguiar et al., 2019). The database reports emissions of CO2 greenhouse gases (GHGs) (Chepeliev, 2022b), non-CO2 GHGs (Chepeliev, 2020b) and air pollutants (Chepeliev, 2021).

To incorporate nutritional accounts within the developed modelling framework, we rely on the method introduced by Chepeliev (2022a). The approach builds on the Food and Agricultural Organization (FAO) Food Balance Sheets (FBS) data and nutritive factors to estimate nutritional content of primary commodities and derived commodities represented in primary commodity equivalent within FBS. Calories, fats, proteins and carbohydrates are estimated and reported. Use categories that account for food, feed, seed, losses and other uses are identified. Food supply is distinguished across GTAP primary commodity sectors, food processing sectors and service sectors that supply food (e.g., restaurants).

FLW are incorporated using a methodology developed by Gatto and Chepeliev (2024). By considering food products in their entirety (i.e., edible and non-edible parts) and excluding non-food biomass flows (i.e., feed, seed, and biomass used for industrial purposes) from FLW. The proposed approach overcomes broadly debated methodological inconsistencies of available FLW estimates (Delgado et al., 2021), providing an important alternative to the estimates from FAO (2011), which are subject to a number of data and methodological limitations (Sheahan and Barrett, 2017; Xue et al., 2017). We define five stages of the FSC to quantify FLW: Agricultural Production, Post-Harvest Handling & Storage, Manufacturing, Distribution & Retail, and Consumption. At the global level, our data collection covers eight commodity groups including cereal crops, horticulture, and animal-sourced foods. Incorporation of the FLW tracing into the analytical framework allows us to estimate both food supply and net intakes at the level of final consumers.

Global economic model

To quantify changes in FLW flows along FSC when transitioning to healthier and more sustainable diets, we use the global computable general equilibrium model ENVISAGE (van der Mensbrugghe, 2024). It is an advanced recursive dynamic variant of the well-known GTAP model (Corong et al. 2017). We run ENVISAGE tailored to tracing biomass flows, maintaining sectoral details for food and non-food biomass activities to capture in detail their responses to changing biomass flows, and sequentially FLW when diets shift. Additional details on the developed modelling framework are provided in Section A of the Supplementary Information. For the current analysis, a specific sectoral and regional aggregation has been developed (Supplementary Information, section B).

Healthier and more sustainable diets and food loss and waste reduction scenarios

We use ENVISAGE to investigate how stand-alone FLW reduction targets, dietary transitions, and a combination of both may change global FLW flows by 2050. Our baseline business-as-usual (**BaU**) scenario follows macroeconomic and demographic projections from a recent update of the SSP database, in particular, relying on the middle-of-the-road SSP2 scenario (IIASA, 2024). We compare our baseline pathway to three scenarios where

FLW generation and dietary shifts are differently targeted. In the **BAU_half_FLW** scenario, we maintain BaU assumptions, additionally introducing a gradual 50% reduction in FLW achieved by 2050. In the **EAT-Lancet** scenario, final consumer demand is adjusted to meet the EAT-Lancet dietary recommendations in accordance with EAT-Lancet targets. This scenario also incorporates enhanced agricultural productivity (compared to the BaU case) and mitigation policies consistent with 1.5C. Finally, in the **EAT-Lancet_half_FLW** scenario, FLW reduction targets and global dietary shifts based on EAT-Lancet targets are simultaneously implemented towards 2050. In each scenario, we assess how FLW targets and dietary changes redirect food flows, changing FLW magnitude, composition, and location. Further details on scenario definition are available in the Supplementary Information (Section D).

Results

The impact of dietary transitions and FLW reductions on FLW magnitude

In our BaU scenario, rising food consumption by 2030 leads to a 13.1% increase in FLW (+306 million tons over 2014-2030 period), with a further rise of 23.4% by 2050 (619 million tons over 2030-2050 period) (figure 1). Across high-income and mid-income regions, the rise in consumption of animal-based products results in a decrease in FLW per unit of gross food consumption (panel A, figure 2), containing the increase in FLW generation. This trend is reverted in Sub-Saharan Africa (SSA) where higher income and population growth results in increasing food consumption across all commodities, including FLW-intensive plant-based products, driving FLW per unit of gross food consumption, as well of total FLW (panel A, figure 2). In low-income regions, but especially in SSA, FLW surges by 217% (547 million tons) by 2050, adding 340 calories per capita per day to wasted food.
Halving global FLW (BaU_half_FLW scenario) boosts food availability, lowers prices, and curbs FLW, especially for plant-based foods. By 2050, global FLW drops by 55.6% (-1.81 billion tons compared to the BaU levels), with the most significant relative reductions in Europe, the Middle East, and North Africa (average -55.4%, figure 1). The largest absolute reductions occur in South Asia, particularly China, where FLW decrease by 128 million tons in 2030 (-20.2%) and 348 million tons in 2050 (-55.3%). Nutritional gains are seen particularly in SSA and MENA, where calorie losses per capita per day decrease by 470 calories by 2050, surpassing the global average reduction of 415 calories lost per day.

The implementation of the EAT-Lancet dietary targets (EAT-Lancet scenario) decreases average food intakes, reducing global FLW by 3.5% (94 million tons) by 2030 and 15.9% (521 billion tons) by 2050 (figure 1). These impacts are more pronounced in high- and upper-mid income countries, where the transitioning to a healthier diet leads to a growing demand for plant-based foods with higher FLW-intensity (panel C, figure 2; red part of the bar), however, this trend is overcompensated by an overall reduction in food demand as net caloric intakes decline (panel C, figure 2; green part of the bar). In addition, changing patterns of trade lead to the outsourcing of the plant-based food production toward low-income regions, such as Africa and Southeast Asia, where these traded foods are increasingly produced by 2050 (see figure 1 and panel B, figure 6).

The EAT-Lancet_half_FLW scenario, combining dietary shifts with FLW reduction goals, leads to the strongest decrease in global FLW compared to stand-alone approaches, cutting global FLW by 23.1% (611 million tons compared to BaU) in 2030 and by 63.2% (2.07 billion tons compared to BaU) in 2050. Lower food demand and calorie intakes imposed by the diet decrease global FLW in comparison to the BaU_half_FLW scenario (-17.1% or 248 million tons in 2050), where food intakes rise based on BaU food demand trends. Similarly, with respect to the EAT-Lancet scenario, the imposition of FLW reduction targets has the most severe effect, reducing global FLW by 20.3% (or 517 billion tons) by 2030, and by 56.2% (or 1.54 billion tons) by 2050 (figure 1). Major absolute reductions are observed in SSA and China where, despite the rise in export-embedded FLW linked to the dietary shift (panel B, figure 6), reduction targets respectively decrease FLW magnitudes by 70.1% (574 million tons) and 59.8% (421 million tons) in 2050. Losses of calories also decline on a global level (an average of 354 calories/capita/day), with peaks observed in SSA (an average of 365 calories/capita/day) and MENA (an average of 407 calories/capita/day).

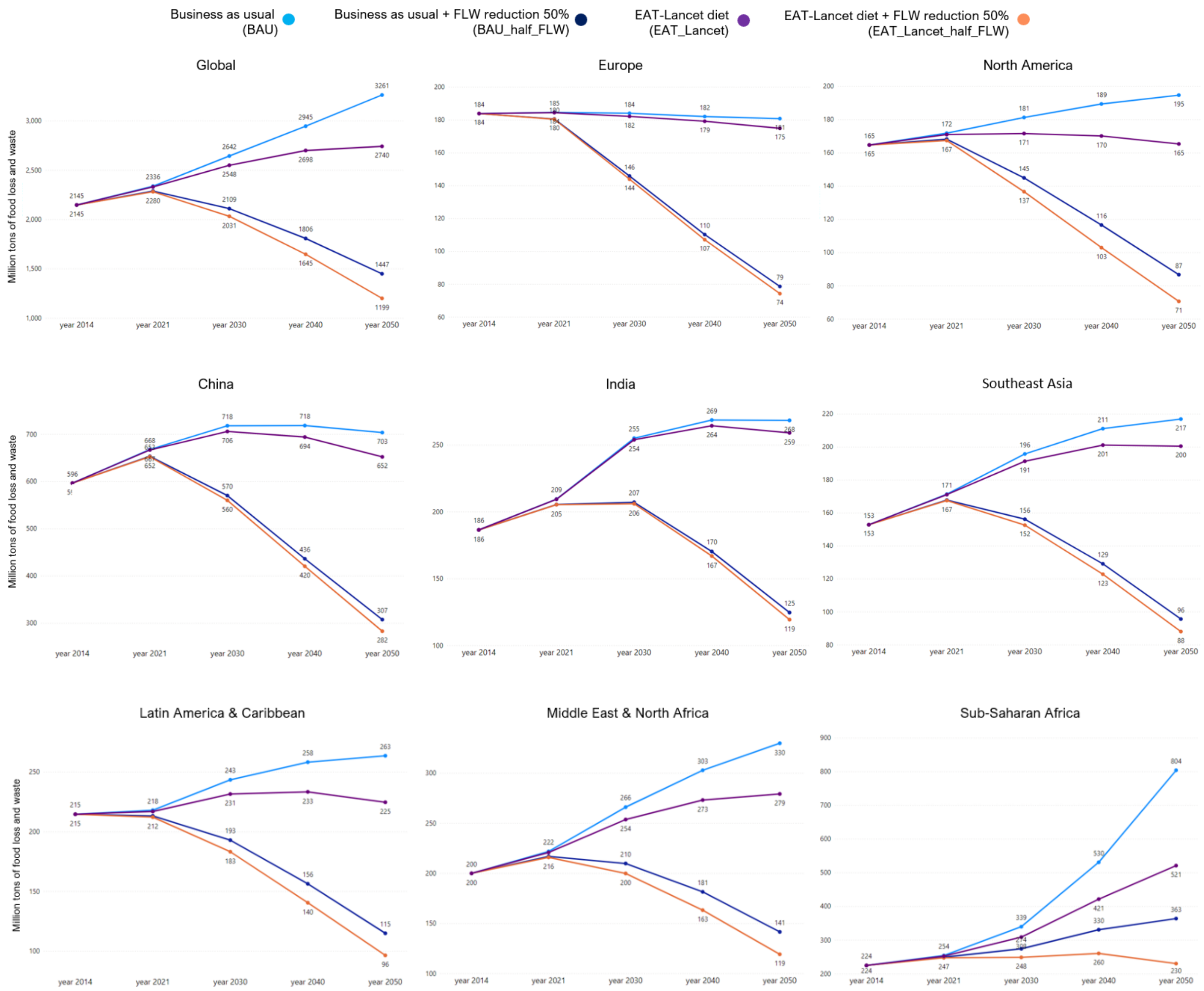

Figure 1. Trends of food loss and waste (million tons) by scenario and region, across investigated years.
Panels illustrate the trajectory of FLW generation (millions of tons) on a global level and in different regions, in the investigated policy scenarios and across the analysed timeframe from 2014 to 2050. The composition of each macro-region is available in the Supplementary information (section B).

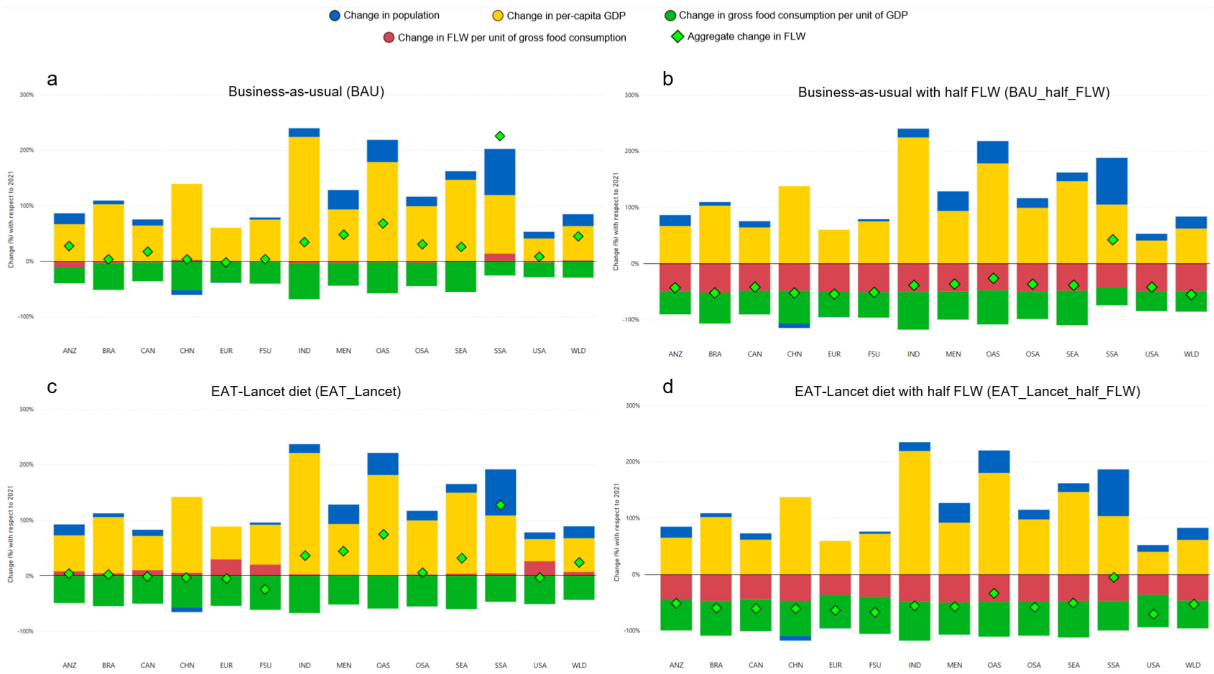

Figure 2. KAYA identity from 2021 to 2050 across investigated scenarios.
KAYA identity (Kaya et al., 1998) illustrating percentage changes in FLW from 2021 to 2050 by region and globally across scenarios based on changes in the main drivers of FLW generation. Panel A reports changes in the Business-as-usual (BaU) scenario. Panel B reports changes in the BaU_half_FLW scenario, where FLW reduction target of 50% are implemented. Panel C reports changes in the EAT-Lancet scenario, where dietary shifts are implemented but no FLW reduction targets are applied. Finally, panel D illustrates changes in the EAT_Lancet_half_FLW scenario where dietary targets and FLW reduction targets are simultaneously implemented. The choice of variables in the KAYA identity is based on a direct comparison with the variables often used in the literature to perform KAYA decompositions of changes in energy-related emissions (IPCC, 2007; Yang et al., 2020; Peters et al., 2017). While 'changes in population' and 'changes in per capita GDP' are kept the same, variables such as 'carbon intensity' and 'energy intensity' have been readapted to our specific study case in the form of 'FLW intensity', that is, FLW generated per unit of food consumed, and 'food intensity', that is, changes in gross food consumption per unit of GDP. Similar approach has been used in Gatto and Chepeliev (2024).

The impact of dietary transitions and FLW reductions on FLW composition

Rising global consumption of processed foods in the BaU scenario, especially in high-income and upper-mid-income regions, drives higher levels of FLW (figure 3), particularly from fruits, vegetables, and nuts (41.4% or 750 million tons), sugar beet/cane (29.8% or 163 million tons), and meat (32.0% and 78 million tons). In lower-mid and low-income regions, FLW mainly consists of crops (30.1%) and fruits and vegetables (28.5%), although shares of animal-sourced foods (ASF) grow to 18.2%, as production-level losses from animal products (+41.6%) and cereals (+23.2%) increase, reflecting higher demand for ASF as incomes rise.
While introducing FLW reduction targets (BaU_half_FLW scenario) leads to a relatively equal reduction across commodities (figure 4), in absolute terms, the most significant impact is observed in reducing FLW from plant-based products, which typically present the highest FLW rates and account for the largest share of global FLW (Gatto and Chepeliev, 2024). Lost and discarded foods from fruits, vegetables, and nuts decrease by 1022 million tons (-55.9%) in 2050, followed by FLW from cereals and grains, which parallelly decrease by 54.2% (or 207 million tons) by 2050 (figure 3). Major reductions of FLW from fruits, vegetables, and nuts are observed in SSA (-342 million tons), China (-291 million tons), and MENA (-94 million tons), with plant-based calorie losses decreasing by an average of 440 calories per capita per day across these regions. Losses of animal-based products globally decrease by 53.1% (177 million tons) in 2050, primarily in high-income regions, such as North America (32.5 million tons) and Europe (24.6 million tons).

The EAT-Lancet diet increases shares of fruit & vegetables and cereals within global FLW, reducing shares of sugar cane and ASF while lowering the average loss of calories embedded in global FLW (-124 calories/capita/day). A stand-alone dietary shift increases global FLW from fruits, vegetables, and nuts by 2050 compared to previous years (figure 3), leading to a relatively smaller decrease of plant-based FLW compared to the BaU_half_FLW scenario in 2050 (average -37.3%, figure 4). Additionally, with respect to BaU in 2050, increasing trends of FLW are observed for oilseeds (+56.1%), other crops (+3.4%), and fish (+9.3%), surpassing BaU levels (cumulative +59 million tons) and resulting in the highest FLW generation for these products across all scenarios by 2050 (figures 3 and 4). Modest increases in FLW are additionally observed for wheat, rising only in Europe and North America by 20.4% (average 7 million tons). In contrast, dietary targets primarily reduce FLW from meat (-69.3% or 112 million tons by 2050), and from sugar cane/beet (-41.7% or 228 million tons by 2050), primarily in South America (-60.1 million tons from sugar cane/beet) and Southeast Asia (incl. China -45.1 million tons from non-ruminant meat).

Combining EAT-Lancet dietary targets with FLW reduction goals (EAT-Lancet_half_FLW) decreases primarily FLW from cereals and grains (-57.6% or 218 million tons) and fruits, vegetables, and nuts (-60.9% or 1104 million tons), reversing the trend of rising plant-based FLW seen in the Eat-Lancet scenario (figure 3 and 4). Animal-based FLW drops sharply by 89.6% (-161 million tons), while FLW from fish and oilseeds also declines, though less than in the BaU_half_FLW scenario due to increased consumption of these products when diets shift (figure 4).

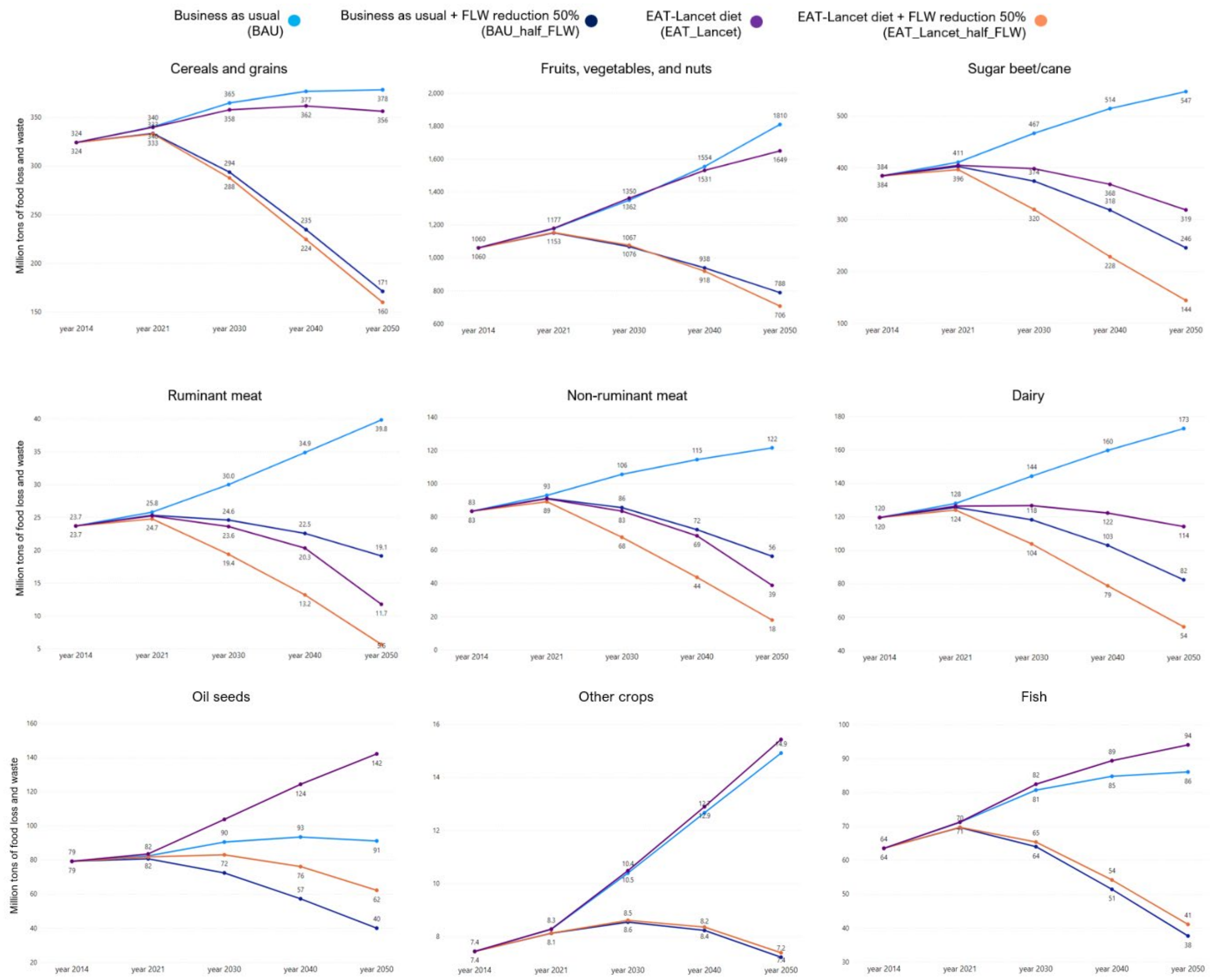

Figure 3. Trends of food loss and waste (million tons) by scenario and commodity, across investigated years.
Panels illustrate the trajectory of FLW (millions of tons) globally generated by the production and consumption of different food commodities, in the investigated policy scenarios and across the analysed timeframe from 2014 to 2050. The composition of each commodity macro category is available in the Supplementary information (section B).

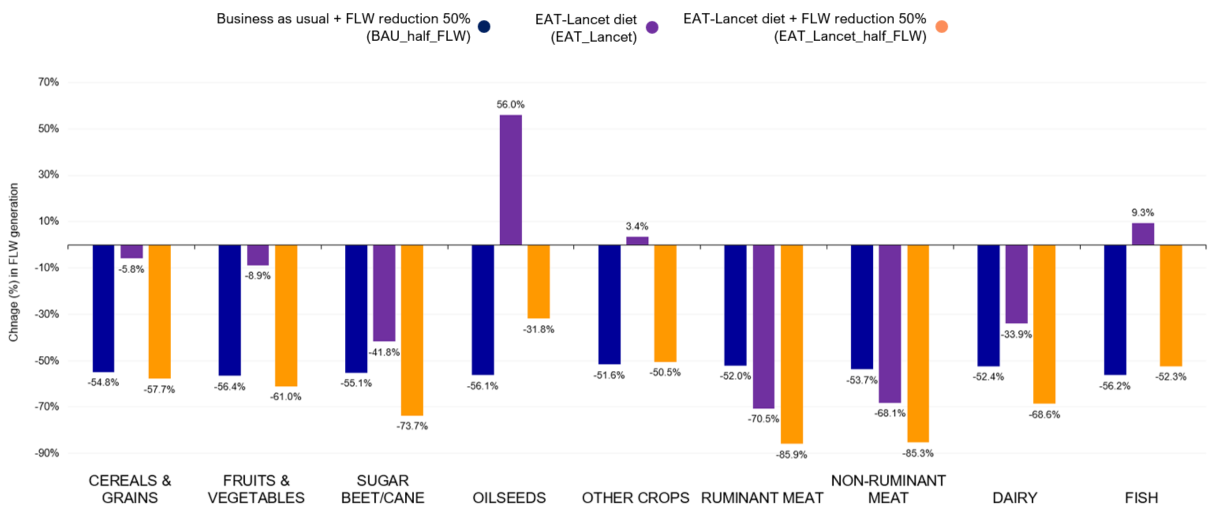

Figure 4. Change in FLW (%) with respect to BaU in 2050 across food commodities and scenarios.
Bars in the graph illustrate the aggregate change in FLW generated by the production and consumption of food commodities at a global level across investigated scenarios with respect to our Business-as-usual (BaU) baseline scenario in 2050.

The impact of dietary transitions and FLW reductions on FLW location

Evolving trends in food demand and global trade significantly influence the location of FLW across supply chain stages. By 2050, increasing food demand in BaU drives farm-level losses at the Agricultural Production and Post-Harvest Handling and Storage stages, particularly from plant-based foods in low-income regions (+60.2% on average), reaching 1.8 billion tonnes globally (around 56.3% of total FLW). Consumer-level food waste increases by 40.1% globally, reaching 0.7 billion tonnes, with high-income regions and upper-mid-income regions responsible for nearly 80% of this waste (figure 5). Export-related losses increase in Brazil and South America reaching 415 million tons, as increasing imports primarily from North America, Europe, and the Middle East, drive losses for sugar beet/cane and fruits, vegetables, and nuts, at the farm-level stages of the supply chain (panel A, figure 6).

Introducing FLW reduction targets (BaU_half_waste scenario) primarily decreases losses at Agricultural Production and Post-Harvest stages, with a total decrease of 57.7% (1.06 billion tonnes) with respect to BaU in 2050 (figure 5). This mainly benefits lower-income regions where the majority of farm-level losses are located. Halving global FLW primarily reduces trade-related losses in regions exporting large volumes of horticultural commodities such as East Asia and Latin America. Export-related losses in these regions decrease by an average of 55.1%, particularly for fruits, vegetables, and nuts in East Asia (including China, -119.8 million tons) and sugar beet/cane in Latin America (-80.1 million tons), both largely driven by import demand from North America, Europe, and the Middle East in 2050. An illustration is provided in the Supplementary Information (figure E2 – section E).

In the EAT-Lancet scenario, a dietary shift toward plant-based products relocates FLW from Manufacturing to Post-Harvest Handling & Storage, as processed food consumption declines and demand for fresh produce increases. In lower-mid- and low-income regions, although food losses at the farm-level decrease by 26.5% (or 222 million tons, figure 5), such stages remain a global hotspot for FLW in 2050. Middle-income regions see a reduction in Post-Harvest Handling & Storage losses (-12.8% or 58 million tons) due to lower food production and exports, while high-income regions experience a moderate increase in farm-level losses (+2.4%), reducing food waste at Distribution and Retail, and Consumption stages (average -40.2% or 52 million tons, figure 5).

Lower global intakes of sugars severely reduce exports-embedded losses from sugar beet/cane in Brazil and Latin America (-58.9 million tons), primarily embedded in exports towards the Middle East (-20.9 million tons), former Soviet Union countries (-7.1 million tons), and India (-7.6 million tons) (panel B, figure 6). However, higher demand for fruits, vegetables, nuts, and oilseeds increases trade-related losses at the early stages of the FSC (51.1 million tons), with stronger effects in Sub-Saharan Africa (+55.0% or 13.7 million tons), China (+6.5% or 5.1 million tons), and Southeast Asia (+7.3% or 4.5 million tons). In these regions, rising losses are driven by rising imports from India (+5.3 million tons), Europe (+4.0 million tons), and the United States (U.S., +1.4 million tons), with U.S. imports also increasing horticultural losses in Latin America (+9.1 million tons).

Combining FLW reduction targets with the EAT-Lancet dietary shift (EAT-Lancet_half_FLW scenario) tempers the reallocation of FLW to early supply chain stages, as halving FLW by 2050 offsets the relocation effects of FLW driven by the dietary transition. Strongest reductions in FLW are observed for farm-level losses (-65.5% or 1.2 billion tonnes), particularly in lower-middle and low-income regions where losses decrease by 68.8% (569 million tonnes) compared to BaU, an additional reduction of 347 million tonnes (-57.3%) compared to the stand-alone EAT-Lancet scenario (figure 5). Reductions in FLW are additionally observed at the Distribution & Retail and Consumption stages, particularly for animal-based FLW (-77.9% or 155 million tons).

Reducing FLW within the global dietary transition (EAT-Lancet_half_FLW scenario) leads to the most significant reduction in trade-embedded FLW, decreasing by 59.7% (or 306.7 million tons) by 2050 (panel C, figure 6). The FLW reduction target outweighs the increase in trade-embedded plant-based losses observed under the stand-alone dietary shift, decreasing the amount of trade-embedded losses across all commodities. Notably, losses from sugar beet/cane exports drop significantly in Brazil (-72.1% or 101.1 million tons), driven by lower import-embedded losses in the Middle East (-36.9 million tons), India (-10.1 million tons), and SSA (-11.9 million tons). Export-embedded losses also decline for cereals (-39.9 million tons) and oilseeds (-14.3 million tons), especially in Europe (-5.5 million tons) and former Soviet Union countries (-8.5 million tons), due to reduced import-embedded losses from the Middle East (-15.3 million tons).

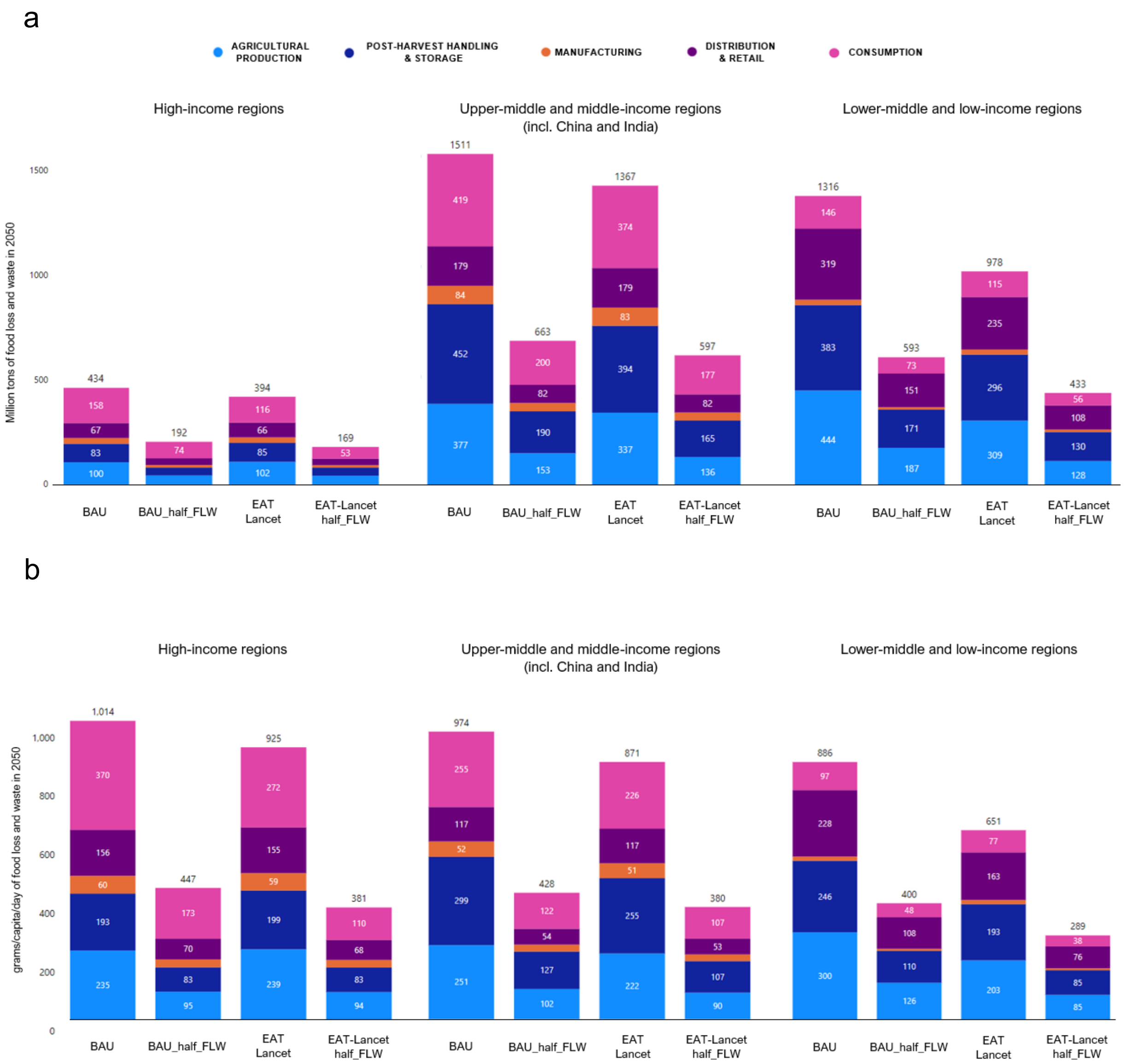

Figure 5. Food loss and waste volumes across stages of global food supply chains by region and income level across investigated scenarios in 2050. Panel A illustrates total magnitudes of FLW (million tonnes) across stages of global supply chains. Panel B illustrates magnitudes of FLW generated per capita per day across stages of global supply chains. The composition of income level regions is available in the Supplementary Information.

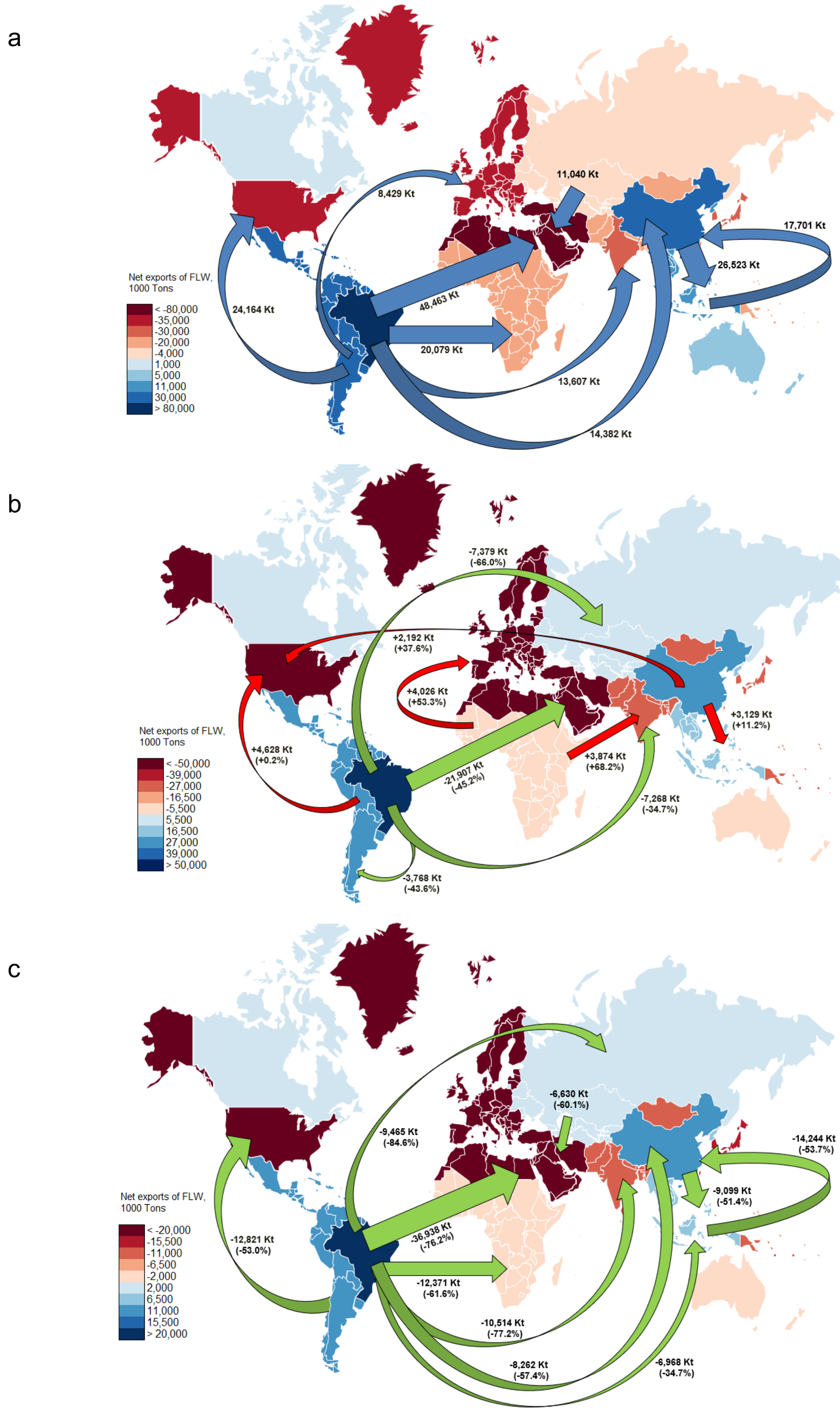

Figure 6. Net exports of food loss and waste (1000 tons) by macro-region across scenarios in 2050. Major flows of trade-embedded FLW (1000 tons and change (%) with respect to BaU in 2050) and FLW-related trade balances (exports of FLW minus imports of FLW) across global regions. The arrows illustrate the direction of the net FLW flows linked to different scenarios in

2050. An arrow from region A to region B indicates that region A is a net exporter of food, hence FLW, to country B. For illustrative purposes, the size of the arrows does not necessarily reflect the magnitude of FLW flows. For this, please note that magnitudes (1,000 t) or percentage changes are reported next to each arrow. Panel A illustrates quantities of net exports of FLW in the BaU scenario in 2050. The blue colour of the arrows in panel A indicates the quantity of FLW flows across different regions. Panel B illustrates changes (1000 tons and percentage) of quantities of net exports of FLW in the EAT-Lancet scenario with respect to BaU scenario in 2050. Panel C illustrates changes (1000 tons and percentage) of quantities of net exports of FLW in the EAT-Lancet_half_FLW scenario with respect to BaU scenario in 2050. In panels B and C, the different colours of the arrows indicate changes with respect to the flows observed in the baseline BaU scenario in 2050. Red arrows indicate an increase of FLW flows, while green arrows indicate a decrease in FLW. The figure for the BAU_half_FLW scenario and additional figures are available in the Supplementary Information (section E).

Discussion

This study bridges the economic and technical modelling of FLW by adding consistent tracing of FLW in physical quantities along global FSC within an economy-wide modelling framework. To our knowledge, this is the first study that explores interactions between FLW reduction measures and global EAT-Lancet dietary transition by 2050, in addition, relying on the newest set of macroeconomic and demographic projections (IIASA, 2024). Our findings suggest that with the continuation of historical trends, FLW along global supply chains is expected to reach 3.26 billion tons by 2050, a 52.1% increase compared to 2014. Adopting healthier and more sustainable diets could reduce FLW by 15.9% by 2050 compared to a scenario where food consumption follows historical trends. However, diet shifts alone are not enough to reverse the overall increase in FLW, as the total amount of lost and discarded food still rises by 2050 compared to 2014 levels. Across regions, spillovers arise in SSA and MENA, where dietary shifts lead to increasing trends of FLW (25.1% by 2050). Particularly in SSA, the sharp rise in population and per-capita GDP by 2050 is expected to increase FLW volumes, even with stand-alone FLW reduction targets.

Combining dietary shift with FLW reduction targets globally reduces FLW by 63.2%, bending the curve of FLW generation requires an integrated strategy combining healthy diets with FLW reductions for effectively reducing spillovers at the global level. Spillover effects are additionally observed across food commodities. FLW from oilseeds, other crops, and fish surpass baseline (BaU) levels (+59 million tons), leading to the highest FLW generation for these products by 2050. As FLW trends for these commodities are declining when FLW reduction targets are implemented, coupling dietary shifts with FLW reduction targets proves to effectively contain commodity-specific spillovers in 2050. Further, spillovers across supply chain stages are found in the rising amount of food losses generated at Agricultural Production and Post-Harvest Handling & Storage in high-income countries. The shift towards healthier diets drives demand for fresh plant-based foods, which are associated with high levels of FLW and results in increasing levels of losses at production stages. As such spillover can be tackled when dietary shifts are combined with FLW reduction targets, stage-specific interventions are necessary to increase the effectiveness of dietary transitions in higher-income regions.

Finally, while demographic trends and increasing wealth play a key role in domestic FLW generation (figure 2), we find additional pressures are generated by changes in global trade. As observable from figure 6, higher exports of plant-based products from SSA and Latin America towards Europe, the United States, and India, increase FLW at the farm level, hampering the hoped reduction pattern induced by the diet. This confirms trade-related spillovers on FLW location under a global dietary shift observed by Gatto et al. (2023), additionally expanding the analysis until 2050. To fully address the spillover effects of FLW caused by the adoption of healthy diets, it is essential to pair a global dietary shift with targeted policies to reduce FLW. Halving FLW yields significant benefits, especially in low-income regions where most plant-based food losses occur during production. Our findings show that these spillover effects are eliminated when FLW reduction targets are implemented alongside dietary shifts. The largest reductions in FLW are seen in China and Sub-Saharan Africa (SSA), with SSA gaining the most, as nutritional availability increases by 365 calories per capita per day, helping to combat malnutrition by 2050.

Contextualizing our results within the framework of the Sustainable Development Goals (SDGs), we find that combining healthier diets with FLW reduction is essential for increasing nutritional availability in low-income regions, supporting progress toward global zero hunger (SDG 2). However, under stand-alone dietary changes, high-income countries (HICs) still contribute to significant FLW in low-income regions through imports, where the potential for FLW reuse is limited. Because trade-embedded FLW is not captured by SDG 12.3, HICs can more easily meet this target, while low-income regions struggle to do so.

Our results highlight several important policy implications. First, we find that under the current set of food-related policies in countries around the world, consumers and producers do not have sufficient incentives to change their behavioural patterns to reduce FLW. Achieving the stated SDG12.3 target of halving FLW by 2030 and even beyond this would require drastic changes in production practices and consumption choices addressing both supply- and demand-side drivers of the FLW. Focus on the former would be more relevant in low-income countries, while demand-side measures would provide more benefits to high-income economies.

Second, transitioning to healthier and more sustainable diets, while a challenging task by itself, is not sufficient to reduce FLW by 2050. Even more, in a number of country-commodity cases, dietary transition could lead to higher FLW volumes as consumers shift toward plant-based foods with higher FLW shares. In this regard, policies promoting healthier diets must consider the potential spillover effects on FLW. Shifts in production, consumption, and trade alter the magnitude, location, and composition of FLW. While dietary shifts can improve nutrition, new technologies and market-based approaches to reuse FLW—whether linked to domestic consumption or trade—can create economic opportunities and environmental benefits. To maximize these benefits, FLW reduction should be central to discussions on dietary transition policies, as spillover effects risk undermining the positive outcomes of a global dietary shift.

Finally, our results highlight heterogeneity in the opportunities for reducing and reusing FLW across countries, commodities and supply stages. Further exploring these differences is crucial to determining where to prioritize FLW-related interventions along the FSC. From the policy perspective, our findings underline the importance of consumption-based FLW accounting, as complementary approach to the widely-used production-based FLW tracing. As with changing diets food production is being outsourced from high-income to low- and mid-income economies, in many cases, optimal FLW-focused interventions could be located in the countries different from those, where the product is consumed by final users.

As with any study, our findings have limitations. In the half FLW scenarios, the projected reduction in FLW assumes technological improvements leading to higher efficiency, without accounting for implementation costs. While this approach risks overlooking price reactions to the implementation costs, it is largely driven by the lack of data on FLW trends under different technologies and their associated costs. In addition, the high level of sectoral aggregation, driven by FLW data limitations, prevents a precise alignment of the EAT-Lancet diet's commodity-specific recommendations with our model. This is particularly evident for horticultural commodities, as we group fruits, vegetables, pulses, nuts, roots, and tubers into a single category simplifying the diet's guidance on individual commodities. Finally, with regard to the provided analysis, we specifically look at FLW, overlooking additional planetary boundaries to contextualise the broader environmental impacts of the diet with and without FLW reduction targets.

A promising area for future research is exploring FLW reductions through market-based mechanisms or technology investments, where reduction policies incur costs. Building on our findings, future studies could additionally focus on specific regions, commodities, or stages of the supply chain to determine when it is more effective to prioritize FLW reduction over reuse. Despite its limitations, this study provides important insights into a better understanding of the synergies and trade-offs between two critical policy areas for the food systems of the future. We outline that FLW plays a key role within global dietary transitions, and advocate for ad-hoc policy packages that are able to simultaneously maximise the benefits of healthier diet while minimising the spillover effects on FLW generation, enhancing the sustainability of global food systems in 2050.

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