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Healthier but wasteful? Changes in food loss and waste along global supply chains with healthier diets

Introduction

Achieving food security in the context of climate change, with limited resource availability for a growing and wealthier global population, requires a system change. Food systems need to be transformed to enhance resilience and sustainability, contributing to the health of people, economies and our planet (World Bank, 2020). Currently, food losses and waste (FLW) generated along global food supply chains (FSC) largely contribute to climate change (Porter et al. 2016) as well as natural resources depletion (Kummu et al., 2012).
Lost or discarded foods endanger economic stability (Parry, James, and LeRoux 2015), undermining social welfare (Lipinski et al. 2013) and threatening the path towards global food security (Foley et al. 2011).

Reducing and reusing FLW to decrease social and environmental burdens represents a global ambition reflected in SDG12 (FAO, 2019). Its actual implementation lies at the core of interlinked socioeconomic and environmental systems and requires a solid understanding of the wider implications such challenge exerts on the global economy (Rutten, 2013) and other SDGs. Increasing global food security (SDG2), for example, may conflict with SDG12 as it inevitably implies the acceptance of certain levels of FLW (FAO, 2019). Simultaneously, tackling FLW may affect food-price stability, possibly intensifying environmental impacts (SDG13, SDG15) and resource use (SDG6, SDG7, SDG14), threatening incomes thus exacerbating global poverty (SDG1). Paradoxically, transitioning towards a more sustainable circular biobased economy (SDG8, SDG12) hinges on significant amounts of FLW to be re-used as production inputs, conflicting with potential reduction targets.

Animal-sourced-food (ASF) is today fundamental for nutrient supply in low-income counties, but it is over-consumed in high-income countries with detrimental health and environmental effects. Shifting towards a more plant-based diet could confer both health and environmental benefits (Willett et al. 2019). It would also increase biomass availability for circular purposes, as plant-based food is generally associated with the highest FLW rates (Delgado, Schuster, and Torero 2020). Nonetheless, if not coupled with an optimal reuse strategy, plant-based FLW can lead to high levels of air and soil pollution (Porter et al. 2016) mitigating the positive effects of a more sustainable diet. As analyses commonly circumscribe to specific challenges, subject-related approaches illustrate magnitudes of problems but neglect comprehensive investigations on market-based trade-offs between FLW and nutritional-environmental targets. Detailing and quantifying FLW along global FSC results therefore fundamental to define which biomass flows can be reused to generate social and economic benefits, as well as determining where along FSC significant FLW reductions profit society and environment. As magnitudes and impacts of FLW mutate accordingly to specific policy interventions, a holistic multidisciplinary assessment capable to quantify FLW while simultaneously analysing related socioeconomic and environmental impacts at each stage of the FSC is required.

Currently, most methodologies adopt physical mass to aggregate FLW data (Parfitt, Barthel, and Macnaughton 2010) ignoring socioeconomic and environmental attributes of FLW. To address this, methodological approaches have focused on estimating FLW impacts adopting indicators calibrated on diverging biophysical, monetary or environmental aggregations. Social and economic assessments where agent behavior, markets and prices are central, provide solutions maximizing utility/welfare while addressing market-related issues but generally gloss over ecological and technical limitations. General equilibrium (GE) models for instance, are proficiently suited for extensive multi-country, multi-sectoral market-based analyses. GE assessments on FLW provide a detailed overview of synergies and trade-offs when several actors, policy instruments and other drivers are operating simultaneously, but tend to misrepresent material balances and technical possibilities, with proposed solutions not exhaustively grasping technicalities and opportunities behind FLW policies.

In contrast, biophysical, nutritional and environmental analyses on FLW [provide detailed investigations on food safety and environmental quality but fail to account socioeconomic drivers of FLW, ignoring value-chain dynamics and stakeholders’ interactions. Such differences in target issues and methodological approaches result in inconsistent estimates and databases (Xue et al. 2017), rendering contents of studies relative to scopes (Corrado et al. 2019), thus difficult to compare. Moreover, as no common FLW definition is globally adopted, methodologies contrast on the inclusion/exclusion of inedible parts of food commodities in FLW flows (Delgado, Schuster, and Torero 2020) and on the (non-)consideration of food flows diverted to other uses (e.g. animal feed) as FLW (Corrado et al. 2019). Such divergences, coupled with different specifications of supply chain stages and different scales of approaches (Delgado, Schuster, and Torero 2020), result in a debate upon the consistency of currently available data.

A consistent database covering technical-biophysical features and monetary values of FLW along global FSC is to date not available. Addressing this fundamental data gap for understanding global FLW changes when policies towards a more sustainable food system are applied, is the focus of this study. We combine FLW biophysical estimates along FSC and link them with data on nutritional content, successively integrating estimates into a consistent economic GE framework. Here we estimate FLW prices respecting physical balances of biomass flows. We assess nutritional, socioeconomic and environmental aspects of FLW when transitioning to a more sustainable diet, improving multidisciplinary modelling of FLW in global computable GE frameworks. We derive global consistent FLW estimates but sacrifice details for single countries, sectors or food commodities, often covered in several case studies. With this new database we explore future FLW trends up to 2030, comparing a *business-as-usual* scenario to a scenario of a global change towards a more sustainable plant-based diet. We finally investigate global synergy effects between nutrition, climate and FLW targets, analysing the global path towards more sustainable food consumption.

To this end, this article is organised as follows. In section two the methodology of the database is illustrated, reporting FLW estimates in physical, nutritional and monetary units. In section three we present estimates of FLW to 2030, testing variations with a sustainable diet scenario (Eat-Lancet diet – Willett et al., 2019). Here, we analyse FLW-related socioeconomic and environmental impacts, outlining implications for different stakeholders along global FSC. Finally, in section four, results are summarised, drawing steps for future research on FLW towards a more sustainable food system.

Materials and Methods

This section presents an overview of the methodological framework adopted in this study. To develop our database, we combine the GTAP Nutritional Database with consolidated data on FLW and estimates of macro and micro-nutritional content from the GENuS database (Smith et al. 2016). These three database steps allow us to derive biophysical amounts (tonnes) and nutritional composition of FLW for several food commodities along each stage of the FSC. By introducing this biophysical data into the global macroeconomic model MAGNET (Woltjer and Kuiper, 2014), we obtain an immediate feedback on market prices of FLW. As so we enhance the ability of an economic model to connect to biophysical models, allowing a computable GE model to capture the technical challenges of transitioning to a more sustainable diet. The multidisciplinary character of our new data is fundamental for improving multilateral analyses on FLW, as biophysical, nutritional, economic and environmental targets can be jointly assessed.

2.1 Definitions

We refer to FLW as *"food (including inedible parts) lost from the food supply chain, comprising pre-harvest losses and excluding food diverted to material uses such as bio-based products, animal feed, seed or sent for redistribution*".
With this classification we align with the European Commission (EC, 2014). We further include losses occurring at pre-harvest stage, identifying losses deriving from non-yields or lower productivity yields hence overcoming a limitation present for example in FUSIONS (2014). We consider only food produced for human consumption including all food types, disposal routes and stages of the FSC, accounting for avoidable (edible) and unavoidable (inedible) FLW. As relevant studies such as (Gustavsson, 2011), (Kummu et al. 2012) or (Lipinski et al. 2013) do not account inedible portions of commodities as FLW, we retain fundamental to consider the entirety of food products, as inedible shares often vary according to countries or cultures and exert environmental pressures when discarded. Moreover, we find inconsistency in the current FLW definition provided by FAO (ref), as it

includes agricultural products originally intended for human consumption and directed to animal feed, but it excludes agricultural products grown for animal feed. For this reason, we exclude from FLW food redirected or produced for other purposes outside human consumption, as such (re)allocation rather prevents biomass from becoming waste. Finally, as data on physical quantities of FLW vary with total food production in turn bounded to socioeconomic and environmental dynamics, we focus on data reporting percentage losses of total food weight. FLW percentages are more stable in the long-term (Fabi and English, 2018) and result better suited for long-term simulations

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