# THE ECONOMYWIDE EFFECTS OF REDUCING FOOD LOSS AND WASTE IN DEVELOPING COUNTRIES

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**Abstract**—One of the Sustainable Development Goals (SDGs) is reducing food loss and waste (FLW) across all stages of food value chains, including the on-farm production, the off-farm postharvest, processing, and distribution, and the household consumption stages. We employ general equilibrium models for Bangladesh, Kenya, and Nigeria to assess the economywide implications of reducing FLW at different stages of value chains. Halving FLW results in GDP increases of between 1.1 and 2 percent, with up to 13 million people lifted out of poverty across the three countries. Diets also improve – especially in Kenya and Nigeria – due to greater availability and lower prices of healthy foods such as fruits and vegetables. Although most of the gains originate from reducing FLW in the on-farm production stage, strong intersectoral linkages mean around 30 percent of measured GDP gains are realized in non-agricultural sectors. Reducing waste at the final consumption stage has small negative impacts on GDP as households purchase less food without reducing their food intake. We conclude that the significant economywide gains provide a justification for adopting FLW reduction strategies, although costing the policy and investment options needed to reduce FLW is an important area for future research.

**Keywords:** food loss and waste; sustainable food systems; poverty; food security; general equilibrium modeling; Bangladesh; Kenya; Nigeria

# 1 INTRODUCTION

Fanzo et al., (2020) describe the food system as comprising of "the people, institutions, environments, infrastructure, and activities that relate to the production, processing, distribution, marketing, sale, preparation and consumption of food". Food systems are influenced by a complex set of external drivers, including demographic, socio-cultural, political, economic, technological, and environmental ones (GOPLAN, 2016). In turn, food systems dictate the availability and affordability of food in local markets and shape preferences and behaviors of consumers.

As such, food systems are crucial in at least two ways. First, food supply chains, which encompass production, storage, processing, and distribution of food, have a tremendous impact on the planet, contributing to climate change and environmental degradation through unsustainable water and land use, biodiversity loss, and emissions and pollution (Godfray, et al., 2010; Tilman, et al., 2011). Second, food environments, that is, the places and contexts in which consumers access food, as shaped by personal circumstances, norms, preferences, markets, and policies, determine what people consume, i.e., their diets. Diets characterized as having deficiencies, excesses, or imbalances in calories or nutrients are a major cause of malnutrition and non-communicable disease and are associated with one-fifth of adult deaths globally (Afshin, et al., 2019; FAO, et al., 2020).

A transformation of food systems is urgently required if countries are to successfully pursue goals of environmental sustainability and healthier populations. Sustainable food systems are defined as ones that provide food and nutrition security for everyone without compromising the economic, social, and environmental needs of future generations (Nguyen, 2018). In short, this means ensuring that all people have access to diets that meet nutritional needs and reduce the incidence of disease and mortality, while simultaneously ensuring that food production and supply chains remain within planetary boundaries (Willett, et al., 2019).

Reducing FLW is central to the United Nations' Sustainable Development Goals (SDGs) (UN, 2022). At least two SDGs relate directly to promoting sustainable food systems: SDG 2 aims to end hunger, achieve food security and improve nutrition; and SDG 12 aims to promote more sustainable consumption and production patterns. The latter also includes as a specific target to "halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" by 2030 (UN, 2022).

While food security has always been a topic of interest for agrifood system analysts, it is only in more recent decades that food security is viewed through a sustainability lens. For example, increased crop productivity is a common recommendation for improving food security, but analysts are now asking how yield gaps can be closed in environmentally sustainable ways (Popp, et al., 2013; Pradhan, et al., 2015). This paradigm shift is shaping debates about efficiency and trade-offs associated with the allocation of resources or outputs. For instance, the food-versus-fuel debate considers the food security and environmental trade-offs in using food crops for biofuel production (Arndt, et al., 2012b; Nonhebel, 2012). Similarly, the national food self-sufficiency debate has historically focused on trade-offs between stability in food supply and efficiency, but increasingly considers environmental consequences of global trade versus domestic production (e.g., Burnett and Murphy (2014); Clapp (2016)).

Another strategic option for simultaneously addressing issues of food security, efficiency, and environmental sustainability is reducing food losses and waste (FLW) along food supply and consumption chains. By some estimates, FLW accounts for up to one-third of the edible parts of food produced for human consumption globally (Gustavsson, et al., 2011), resulting in roughly US$1 trillion in economic losses per year (Lipinski, 2020). These astounding estimates have spurred interest in FLW reductions as an alternative to increased crop production—and the associated environmental pressures—to feed a growing global population and improve diet quality.

Recent methodological advancements have made it easier to quantify the extent of FLW at different stages in the food supply and consumption chain (Gustavsson, et al., 2011; Fabi & English, 2018; Lipinski, 2020; Bodirsky, et al., 2020). This has also made it easier to consider the implications of FLW on sustainable use of natural resources (i.e., land and water) or on food security (e.g., in terms of calories foregone). Such estimates provide an important benchmark for estimating the economic, environmental, or food security consequences of reducing FLW. However, there is still much to learn. First, most existing studies measure losses within value chains independently from one another. Given linkages across agrifood value chains, the scale of the problem is potentially underestimated. A general equilibrium approach that captures these linkages is justified both by economic theory (Rutten, 2013) and by a handful of studies that have employed (global) economywide models (Rutten & Mhlanga, 2015; Rutten & Kavallari, 2016; Springmann, et al., 2018; Kuiper & Cui, 2021). Second, most studies provide global or regional perspectives on the problem, whereas the nature and extent of FLW varies by country because of structural differences in their agrifood systems. Moreover, policy measures are adopted at national level and so analysis conducted at national level may provide more compelling evidence.

This study partially fills these research gaps. We employ economywide models for Bangladesh, Kenya, and Nigeria to assess the GDP, poverty, and food security implications of halving FLW along various stages of domestic food supply chains, including the on-farm production stage, the off-farm postharvest, processing, and distribution stages, and the household consumption stage. The simulations are consistent with the SDG target of halving food waste at retail and consumer levels. We assume the same loss reduction in production, postharvest, and processing stages, even though the SDGs are less specific in that regard, stating merely that losses will be reduced.

The scenarios draw on FLW estimates by product type and supply chain stage for each country, which we estimate from food quantity estimates in the Food and Agriculture Organization (FAO) Food Balance Sheets (FBSs) (FAO, 2022a) following a method by Aragie and Balie (2018). The use of economywide models ensures that the benefits, as well as the trade-offs and unintended consequences of reducing FLW, are captured. For example, FLW reductions at one stage of the food supply chain may affect market conditions, output, and employment in both upstream and downstream sectors of the chain. Similarly, there may be trade-offs and synergies across development outcomes, such as growth, poverty, or food security, which we track with the aid of the model.

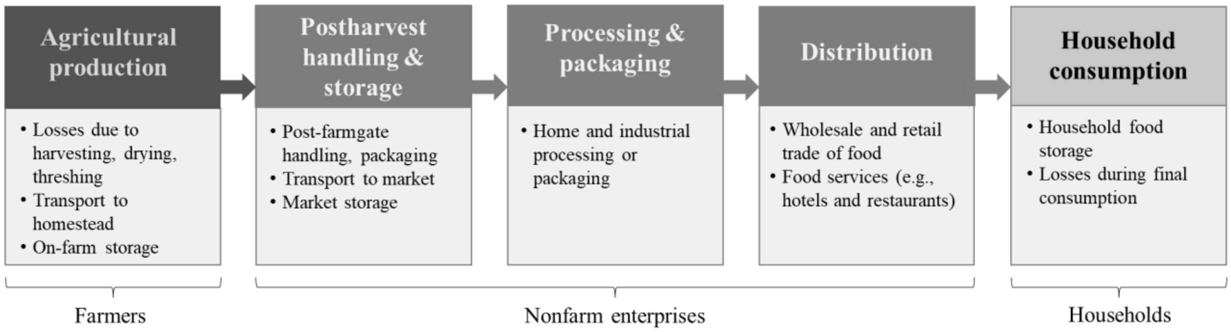
The remainder of the paper is organized as follows. Section 2 presents theoretical concepts and estimates of FLW along various food supply chain stages in our three case study countries. Section 3 introduces the modeling approach and simulations for assessing the economywide effects of FLW reductions, from macroeconomic and sector-level (e.g., in terms of GDP and employment) to household-level (e.g., poverty and food security). Section 4 presents detailed model results, while Section 5 concludes.

# 2 MEASURING FOOD LOSS AND WASTE

## 2.1 Food loss and waste along food supply chains

The first step in our analysis is obtaining baseline estimates of FLW in the case study countries. We are interested both in total losses by food group or value chain and where these losses occur within the different stages of food supply and consumption chains, i.e., the on-farm production stage, the off-farm postharvest, processing, and distribution stages, and the household consumption stage. Figure 1 details the types of losses typically recorded within each of these stages. Since the latter stages often entail some degree of processing and transformation of foods, FLW in all stages are expressed in terms of the primary equivalent volume of supply at the agricultural production stage to facilitate comparison across stages.

**Figure 1. Stages in the food supply and consumption chain and associated food waste and losses**




**Source:** Authors compilation

Food losses occurring in the agricultural production stage include losses due to damage or spillage during harvest operations. It also includes losses incurred during on-farm transportation or storage. Losses incurred at the agricultural production stage lower farm profits since they occur before the product is marketed. Post-harvest handling and storage losses occur off the farm. This includes losses incurred during handling between the farmgate and the market and those incurred by traders during storage. Losses incurred in the processing and packaging stage relate to spillage or degradation of products during industrial and domestic processing. The distribution stage includes losses associated with trade and transport of processed foods and food waste in the hospitality sector.[1] Food waste in the household consumption stage occurs during food storage at home and preparation for final consumption. These losses require households to purchase more food than what they ultimately ingest.

The distribution of losses across the various stages is often dependent on the type of food under consideration, the level of economic development in a country, and the quality of infrastructure. For example, losses will differ by food type and food supply chain stage depending on the perishability of the food type or the extent of processing and transportation required to bring those foods to final consumers. Generally, as economies transform, a greater share of farm produce is marketed, which means more of the waste is transferred to the off-farm sector. Poor quality storage, industrial equipment, or transport infrastructure in a country may also cause losses to be concentrated in the off-farm stages. In wealthier countries, more food is consumed away from home, which suggests losses may be relatively larger in the distribution stage. Wealthy households (or counties) may also have less incentive to avoid food losses since food expenses make up a smaller share of their household budgets.

## 2.2 Data and estimation methods

There are several potential sources of FLW information. Household income and expenditure surveys frequently capture information on farmers' estimates of on-farm production and storage losses (Christiaensen & Demery, 2018; Bachewe, et al., 2020). However, measuring FLW is not necessarily a primary objective of these surveys, and hence the relevant questions may be limited in scope. Dedicated FLW surveys conducted at country level, on the other hand, may provide more accurate estimates of FLW, but these do not necessarily cover all food groups or all food supply chain stages (Abass, et al., 2014; Gummert, et al., 2020; Minten, et al., 2021; Shee, et al., 2019). FLW estimates from these surveys may also not be comparable across food supply chains or countries due to differences in data collection or estimation methods. In contrast, regional initiatives such as the Africa Post Harvest Loss Information

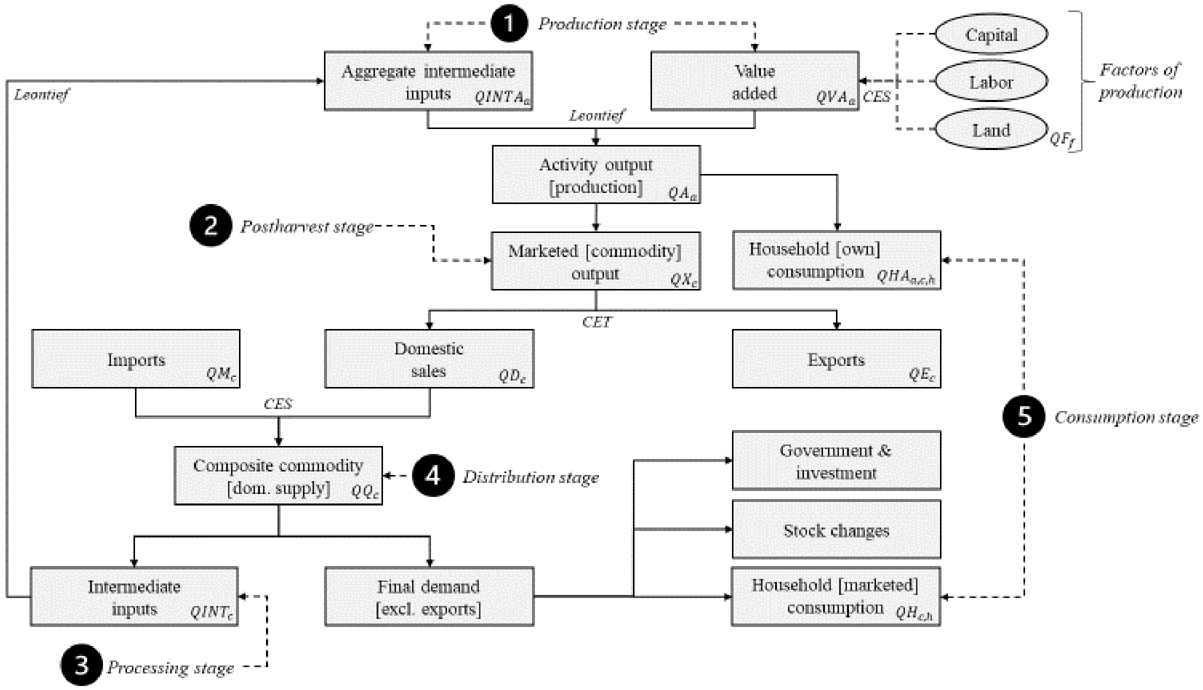
[1] These include losses in the market system, including wholesale, supermarkets, retailers, and wet markets. Losses during eating out in hotels and restaurants or festival consumption also fall under this category. The consumption stage of food waste refers to such waste during consumption at the household level.

System (APHLIS) do produce data suited for cross-country comparisons (APHLIS, 2022), but this database only covers cereal crops and does not track losses along the different food supply chain stages.

Given limitations of these existing data sources, coupled with our interest in measuring effects of FLW reductions across all stages of all food chains using a replicable method that generates comparable results, we rely on FAO FBSs (FAO, 2022a) and adopt an approach piloted by Kummu et al. (2012) and refined by Aragie and Balie (2018) to construct our own baseline estimates of FLW in Bangladesh, Kenya, and Nigeria. The FBSs provide product flow data for virtually all countries and for a comprehensive range of vegetal and animal products. The method we adopt for estimating FLW is easily replicable across all these countries. The FBSs further record both the sources of food commodities in domestic markets (e.g., from domestic production or imports) as well as their uses (e.g., as intermediate inputs, exports, stock changes, or final household consumption), which allows us to estimate food quantities – or product flows – at every stage of the food supply and consumption chain.

Figure 2 is a graphical representation of those product flows. This framework also represents the way in which domestic production and marketed commodity flows are captured in the computable general equilibrium (CGE) model we introduce in Section 3. At the production stage ① intermediate inputs and factors of production (value added) combine to form activity output (or domestic production). Activity output leaves the farm (or factory) gate and is transformed into marketed commodity output in what we term the postharvest stage ②. From here output is allocated either to domestic or export markets. Domestic sales combine with imported food products, which together constitute domestic supply. In the distribution stage ④ those food items not yet considered final products are demanded by food processors as intermediate inputs, and hence re-enter the production system. We refer to this as the processing stage ③ to differentiate it from the production stage, which in our terminology is defined as on-farm production only. Final products are either retained as stocks (e.g., in the case of grains) or consumed by households in the consumption stage ⑤. Government and investment demand also forms part of final demand, but typically only includes nonfood commodities and services.

**Figure 2. Product flows and food supply stages in which food loss and waste can be reduced**




**Source:** Authors' representation
**Notes:** CES = constant elasticity of substitution; CET = constant elasticity of transformation. Variable names in the boxes are from the CGE model. See Section 3.2 and Appendix 7.2 for further details.

For our baseline FLW estimates we aggregate the product flow data for detailed food items into eight food groups, namely cereals, roots and tubers, oilseeds and pulses, fruits and vegetables, meat products, fish and seafood, dairy products, and other foods (see Table A1 in Appendix 7.1 for a detailed mapping to FBS items). We further use five-year averages of product flow data in the FBSs (i.e., for 2015–2019) to limit the effect of possible outliers. Once baseline food quantities (product flows) have been estimated for each stage in the food supply and consumption chain, we estimate the marginal FLW quantities in each food supply chain stage by applying average FLW factors estimated by Gustavsson et al. (2011). These are reported for the Sub-Saharan African and Asian regions, which we respectively apply to Kenya and Nigeria and to Bangladesh data (see Table A2 in Appendix 7.1). The resulting baseline FLW estimates for Bangladesh, Nigeria, and Kenya are presented in the next section.

## 2.3 Baseline food loss and waste estimates

Although Bangladesh, Kenya, and Nigeria are all classified as lower-middle-income countries, the GNI per capita is significantly lower in Kenya (USD 2,008) and Nigeria (USD 2,100) than in Bangladesh (USD 2,619) (World Bank, 2022). The higher level of economic development in Bangladesh is also reflected in other indicators. For example, in Bangladesh agriculture contributes only 13.5 percent to GDP, compared to 22.3 and 23.1 percent in Nigeria and Kenya. Likewise, the headcount poverty rate, measured at the international poverty line (USD 2.15 per person per day) is 14.3 percent in Bangladesh, compared to 36.8 and 39.1 percent in Kenya and Nigeria. Bangladesh and Nigeria count among the top-ten largest countries in the world by population, with populations of 166.3 and 211.4 million, respectively, compared to Kenya's 55.0 million. Our case study countries, therefore, represent around 126.7 million or almost one-fifth of the world's poor population.

Table 1 presents baseline FLW estimates. Total FLW as a percentage of total supply is highest in Nigeria (32.8 percent), which equates to 69.2 million tons of food lost each year. Losses are lower in Kenya (27.6 percent or 9.2 million tons) and Bangladesh (19.4 percent or 21.2 million tons). Whereas in Bangladesh cereals account for the largest share of FLW (39.6 percent), roots and tubers account for the bulk of losses in Nigeria (67 percent). Fruit and vegetable losses are large relative to their supply shares in all countries, which reflects large loss factors for this commodity group (see Table A2 in Appendix 7.1). FLW shares are also relatively large for roots and tubers and, in the case of Bangladesh, for fish and seafood. In contrast, FLW shares of cereals, oilseeds and pulses, and dairy products are relatively small.

The second part of Table 1 breaks losses down by food supply chain stage. Since the primary equivalent food supply is the same in every stage, only the total value is shown in the table. The FLW rates in this part of the table are additive across the stages, i.e., they represent the marginal loss incurred in each stage. The key result here is that FLW rates are highest in the production and postharvest stages. These two stages also account for the bulk of overall losses, ranging from 62.1 percent in Bangladesh and Kenya to 76.5 percent in Nigeria.

As we elaborate in the next section, the FLW shares are important for interpreting model results since the simulations all entail a halving of baseline FLW at each stage in the food supply chain. Our expectation, therefore, is that FLW reductions will have the greatest economywide impact when they occur in the production and postharvest stages of the supply chain. In contrast, the economywide benefits of halving FLW at the consumption stage are likely to be small, although the direct socioeconomic benefits to individual households may be significant. Of course, FLW reductions in any stage may have spillover implications for other stages or sectors of the economy, both within and outside of the agrifood system. By using an economywide model we can assess the broader implications of reducing FLW at every stage.

**Table 1. Annual food loss and waste estimates for Bangladesh, Kenya, and Nigeria**

| | Bangladesh | | | | | Kenya | | | | | Nigeria | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Food supply (tons) ('000s)* | *FLW tons ('000s)* | *Food supply share (%)* | *FLW share (%)* | *FLW % of food supply* | *Food supply (tons) ('000s)* | *FLW tons ('000s)* | *Food supply share (%)* | *FLW share (%)* | *FLW % of food supply* | *Food supply (tons) ('000s)* | *FLW tons ('000s)* | *Food supply share (%)* | *FLW share (%)* | *FLW % of food supply* |
| By food group | | | | | | | | | | | | | | | |
| Cereals | 65,062 | 8,393 | 59.5 | 39.6 | 12.9 | 7,720 | 826 | 23.2 | 9.0 | 10.7 | 32,634 | 4,275 | 15.5 | 6.2 | 13.1 |
| Roots & tubers | 10,217 | 3,770 | 9.3 | 17.8 | 36.9 | 3,479 | 1,569 | 10.5 | 17.1 | 45.1 | 116,108 | 46,327 | 55.0 | 67.0 | 39.9 |
| Oilseeds & pulses | 6,650 | 685 | 6.1 | 3.2 | 10.3 | 2,185 | 389 | 6.6 | 4.2 | 17.8 | 22,360 | 4,718 | 10.6 | 6.8 | 21.1 |
| Fruits & veg. | 11,097 | 4,461 | 10.2 | 21.1 | 40.2 | 5,586 | 2,268 | 16.8 | 24.8 | 40.6 | 27,845 | 10,776 | 13.2 | 15.6 | 38.7 |
| Meat products | 1,443 | 215 | 1.3 | 1.0 | 14.9 | 1,055 | 288 | 3.2 | 3.1 | 27.3 | 2,311 | 624 | 1.1 | 0.9 | 27.0 |
| Fish & seafood | 4,192 | 1,266 | 3.8 | 6.0 | 30.2 | 165 | 45 | 0.5 | 0.5 | 27.2 | 1,876 | 437 | 0.9 | 0.6 | 23.3 |
| Dairy products | 3,589 | 628 | 3.3 | 3.0 | 17.5 | 5,128 | 1,205 | 15.5 | 13.2 | 23.5 | 519 | 120 | 0.3 | 0.2 | 23.1 |
| Other foods | 7,100 | 1,768 | 6.5 | 8.4 | 24.9 | 7,845 | 2,573 | 23.7 | 28.1 | 32.8 | 7,312 | 1,923 | 3.5 | 2.8 | 26.3 |
| *Total (average*)* | *109,350* | *21,186* | *100.0* | *100.0* | *19.4** | *33,163* | *9,163* | *100.0* | *100.0* | *27.6** | *210,964* | *69,200* | *100.0* | *100.0* | *32.8** |
| By food supply stage | | | | | | | | | | | | | | | |
| Production | - | 6,278 | - | 29.6 | 5.7 | - | 2,943 | - | 32.1 | 8.9 | - | 26,222 | - | 37.9 | 12.4 |
| Postharvest | - | 6,881 | - | 32.5 | 6.3 | - | 2,749 | - | 30.0 | 8.3 | - | 26,724 | - | 38.6 | 12.7 |
| Processing | - | 3,230 | - | 15.3 | 3.0 | - | 1,372 | - | 15.0 | 4.1 | - | 7,188 | - | 10.4 | 3.4 |
| Distribution | - | 3,162 | - | 14.9 | 2.9 | - | 1,726 | - | 18.8 | 5.2 | - | 7,019 | - | 10.1 | 3.3 |
| Consumption | - | 1,635 | - | 7.7 | 1.5 | - | 372 | - | 4.1 | 1.1 | - | 2,044 | - | 3.0 | 1.0 |
| *Total* | *109,350* | *21,186* | *100.0* | *100.0* | *19.4* | *33,163* | *9,163* | *100.0* | *100.0* | *27.6* | *210,964* | *69,200* | *100.0* | *100.0* | *32.8* |

**Source:** Authors' estimates based on FAO (2022a) and Gustavsson et al. (2011).

**Note:** Values with * are country level average percentages of FLW in total food supply.

# 3 MODELING FOOD LOSS AND WASTE REDUCTION

## 3.1 Model description

The objective of the modeling exercise is to examine the economywide effects of reducing FLW at various stages of food supply and consumption chains. We measure both the direct and indirect economic benefits as well as the trade-offs associated with reduced FLW across all markets and actors in the economy. For this we use the static version of IFPRI's Rural Investment and Policy Analysis (RIAPA) model (IFPRI, 2022). At the core of RIAPA is a single-country computable general equilibrium (CGE) model that incorporates flexible behavioral features, such as nested production functions for agricultural and nonagricultural activities, imperfect substitution between domestic and traded commodities, and a linear expenditure system of consumer demand. Consumers and producers maximize utility and profits based on factor and product prices, which adjust endogenously to establish market equilibrium (for details, see Lofgren et al. (2002)). The choice of a static over a recursive-dynamic model is justified for an impact assessment of FLW reductions as results are unaffected by modeling assumptions about population growth rates and structural transformation of economies (Kuiper & Cui, 2021).

The CGE model is calibrated to recent Social Accounting Matrixes (SAMs) for Bangladesh (Dorosh, et al., 2021), Kenya (Pradesha, 2021), and Nigeria (Thurlow, 2021). These economywide databases capture detailed transaction flow data (incomes and expenditures) for different actors (e.g., firms or activities, households, government, and the rest of the world) as they interact via commodity and factor markets. The SAMs used in this study were produced under the IFPRI-led Nexus Project and have similar structures. Each has around 30 agricultural sectors, up to 40 industrial sectors, including 18 agroprocessing sectors, and 12 services sectors. We consider the agricultural sectors, the agroprocessing sectors, and the services sectors engaged in food trade and transport or restaurants to all form part of the broader agrifood system. The SAMs further include accounts for agricultural land, agricultural and non-agricultural capital, and eight labor groups (split by rural and urban areas and four education categories). The SAMs also include 15 representative household groups.

The CGE model produces results on sectoral growth and employment outcomes. The model further produces results on changes in real household consumption expenditure. From these results, we estimate associated poverty and food security outcomes by linking results to survey-based microsimulation modules. This is done by linking each individual household in the respective surveys—i.e., the 2016 Household Income and Expenditure Survey for Bangladesh (BBS, 2017), the 2016 Integrated Household Budget Survey for Kenya (KNBS, 2018), and the 2015 Living Standards Measurement Survey for Nigeria (NBS, 2016)—to its representative household group in the CGE model. Modeled changes in food and nonfood consumption are then applied to the reported consumption levels of individual households in the survey and a microsimulation model computes changes in poverty or food security outcomes indicators. The poverty module follows Arndt et al. (2012a) and produces poverty headcount rates and depth of poverty estimates by population subgroup (we report the former). The diet module produces a Reference Diet Deprivation (ReDD) index, a multidimensional indicator that measures the shortfall in a household's calorie consumption against recommended calorie intakes for six key food groups, namely staples, fruits, vegetables, dairy, protein foods, and added fats (Pauw, et al., 2021). Lastly, the hunger module produces estimates of the Prevalence of Undernourishment (PoU), i.e., the share of households that consume fewer calories than what is required for a healthy life (FAO, 2022b). Household expenditures in the poverty module and household calorie availability in the diet and hunger modules are all adjusted for the age and gender composition of the household.

## 3.2 Simulation design

Simulation analysis of FLW reductions is still in its infancy (Rutten & Mhlanga, 2015). A handful of studies have examined the effects of FLW reductions at the primary and processing stages using global models, including general equilibrium (Kuiper & Cui, 2021; Rutten & Kavallari, 2016) and partial equilibrium ones (Springmann, et al., 2018). Britz et al. (2019) also employed a global general equilibrium model for the European Union to simulate the effects of food waste reductions in the consumption stage. Our analysis contributes to this modeling literature in two ways. First, we consider loss reductions separately within and simultaneously across all stages of all food supply and consumption chains. As we detail in the remainder of this section – with a technical description and accompanying equations in Appendix 7.2 – this is achieved by adjusting a variety of efficiency parameters, shift parameters, input-output coefficients, and marginal budget shares in the CGE model such that the FLW estimates implicit in the baseline products flows in the model are reduced by 50 percent. Second, we model impacts using country general equilibrium models that account for the unique structural features of the respective economies. Our country models also have a more detailed economic structure than is typically reflected in global models, which allows us to produce more refined country-specific results.

*Production scenario:* FLW reductions at the agricultural production stage are associated with reduced harvesting and on-farm transport and storage losses. Reducing FLW implies an efficiency gain in that a given amount of a farmer's production, or activity output, can be produced using intermediate inputs and primary factors of production, such as capital, land or labor (see ① in Figure 2). Therefore, for this scenario we increase total factor productivity, which raises the value added per unit of primary input. We simultaneously lower the quantity of aggregate intermediate input required per unit of farm output by a factor proportionate to the total factor productivity gain to account for increased intermediate input use efficiency (see Equations 1a–1b in Appendix 7.2). Both subsistence farmers producing for their own consumption and commercial farmers producing for the market experience these efficiency gains.

*Postharvest scenario:* FLW reductions at the postharvest handling and storage stage are associated with lower spillage and degradation during handling, storage, and transportation between the farm gate and the distribution stage. The balance of activity outputs not consumed by farming households themselves is marketed. Reduced FLW in the postharvest scenario therefore means greater quantities of food products that leave the farm gate are available as marketed commodities. Marketed commodities are supplied to domestic or export markets as governed by a constant elasticity of transformation (CET) function in the model (see ② in Figure 2). We adjust the shift parameter in the CET function such that the quantities of food in domestic and export markets increase per unit of activity output (see Equations 2a–2c in Appendix 7.2). These gains apply to all primary and processed food products produced in the economy.

*Processing scenario:* The food processing stage entails a reduction in waste of foods used as intermediate inputs by producers of food and nonfood products. Fixed input-output coefficients in the CGE model define the quantities of intermediate inputs required per unit of output. In the processing scenario the input-output coefficients for food inputs are reduced to reflect their more efficient use (see ③ in Figure 2 and Equation 3 in Appendix 7.2). This results in a reduction in demand for food commodities used as intermediate inputs.

*Distribution scenario:* FLW reductions in the distribution stage result in an increase in total the quantity of food available domestically for use as intermediate inputs or final domestic demand. This supply originates from a so-called composite commodity of imported and domestically produced foods. The optimal mix of imported versus domestically produced commodities in the composite commodity is governed by a constant elasticity of substitution (CES) function in the model (see ④ in Figure 2). The distribution scenario adjusts the shift parameter in the CES function so that the composite food commodity available for domestic consumption increases per unit of imports and domestic supply (see Equation 4 in Appendix 7.2).

*Consumption scenario:* Lastly, the consumption scenario entails reduced food waste during final consumption by households. By wasting less, households can reduce their food expenditure without sacrificing food intake. We model this by lowering food budget shares in the household demand function so that households consume less food from own production or demand less food from the market for a given level of disposable income (see ⑤ in Figure 2 and Equations 5a-5c in Appendix 7.2). Only the budget shares of households in the third through fifth expenditure quintiles are adjusted under the assumption that the opportunity cost of food waste is high for poor households.

Two points are worth noting regarding the consumption scenario. First, savings from reduced food spending are reallocated across all commodities – including food – based on consumption preferences, which means the decline in food expenditure will be proportionately less than the reduction in food waste. However, the likely outcome is still a net decline in demand for food for a given level of disposable income. Second, although food spending declines, the food quantities ingested increase, or at least remain unchanged since less food is wasted. The microsimulation models account for changes in food intake when generating results on poverty, diet deprivation, and hunger.

Since the simulation parameters are calibrated to produce a 50 percent reduction in baseline FLW estimates, the scenarios are essentially efficiency gain scenarios where the implied efficiency gain is proportionate to the initial loss in a food supply. Since average losses are largest in Nigeria (see Table 1), the implied efficiency gains from halving FLW are also largest in Nigeria, and hence we expect the relative economic benefits to also be largest in Nigeria. Table 2 presents estimates of the average implied efficiency gain across all food sectors and by food supply chain stage. These are essentially the half the commodity-weighted, country-specific average loss factors (shown in Table A2 in Appendix 7.2).

**Table 2. Implied efficiency gains of food loss and waste reductions scenarios**

| | Implied efficiency gains (%) by scenario | | | | |
|---|---|---|---|---|---|
| | Production | Postharvest | Processing | Distribution | Consumption |
| Bangladesh | 2.9 | 3.2 | 1.5 | 1.5 | 0.8 |
| Kenya | 4.4 | 4.2 | 2.1 | 2.6 | 0.6 |
| Nigeria | 6.2 | 6.3 | 1.7 | 1.7 | 0.5 |

**Source:** Authors' estimates

# 4 RESULTS AND DISCUSSION

## 4.1 Economic impacts

Table 3 summarizes the key economic impacts of FLW reductions, including on consumer prices, exchange rates, GDP at market prices and factor costs, and employment. Halving FLW across all food supply stages has substantial economywide effects, raising GDP at market prices by 3.1 to 5.3 percent and GDP at factor cost by 1.1 to 2 percent across the three case study countries. As expected, relative gains are larger in Kenya and Nigeria because of the larger implied efficiency gains in these countries (see Table 2). By comparison, Kuiper and Cui (2021) estimate a 0.6 percent increase in GDP at factor cost if food losses in primary production and processing decline by 25 percent in Sub-Saharan Africa.

The largest gains in GDP are recorded in the production stage. These gains are linked to increased productivity and value addition on farms, which is measured as GDP at factor cost. It is noticeable that the gap between the change in GDP at market prices and GDP at factor costs is not large in this stage. GDP gains in the remaining food supply stages are not only smaller, but the gap between the change in GDP at market prices and factor costs widens. In these off-farm stages, economic gains are primarily associated with reduced losses of foods already produced, i.e., there is no further productivity gain or supply increase on farms that would result in an increase in GDP at factor cost. However, the marketed supply or availability of foods increases, which raises GDP at market prices.

Whereas FLW reductions cause marginal increases in the consumer price index in Bangladesh and Nigeria, prices fall by 0.6 percent in Kenya. Generally, FLW reductions at the production and postharvest stages lower food prices, but these reductions are more than offset by increases in nonfood prices, which causes the overall price index to increase. FLW reductions in the other stages—especially the distribution stage—have the opposite effect as food trade and services sectors become more efficient.

We also observe changes in exchange rates, which affect domestic prices. Reductions in food losses at the production and postharvest stages cause the exchange rate in Bangladesh and Nigeria to depreciate by up to 1.3 percent. This causes imports to become more expensive, resulting in an increase in domestic prices. Much smaller exchange rate movements—in both directions—are observed in the remaining food supply chain stages, although in the combined scenario, the exchange rate still depreciates in Bangladesh and Nigeria. By contrast, the exchange rate appreciates because of FLW reductions in almost all the food supply chain stages in Kenya, with a 3.2 percent appreciation overall. Kenya has relatively large tea and coffee export sectors, and so on-farm productivity gains or postharvest efficiency gains lead to improvements in the trade balance. Efficiency gains in the distribution stage also allow Kenya to substitute food and agricultural imports with domestic supply, which causes the exchange rate to strengthen further.

Table 3 also reports changes in GDP at factor cost at the subsector level. In the combined scenario, GDP in the agrifood sector expands by 2.7 percent in Bangladesh and by 5.3 percent in Kenya and Nigeria. In all three countries, the on-farm component (primary agriculture) expands more rapidly than the off-farm component of the agrifood system, with most of that expansion explained by FLW reductions in the production stage. The off-farm component includes such sectors as agroprocessing, food trade and transport, and food services. The weaker performance of the off-farm component relates to declining demand for food and agricultural products as processors become more efficient and consumers reduce their food waste. This reduced demand also explains the low or even negative impact on GDP in the primary agricultural sector when FLW reductions occur in the off-farm stages of the food supply chain.

**Table 3. Economic impacts: Prices, exchange rates, GDP, and employment effects**

| | Initial value | Deviation from initial value (percent) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Produc-tion | Post-harvest | Processing | Distribu-tion | Consump-tion | Combined |
| Bangladesh | | | | | | | |
| Consumer price index | 1.0 | 0.2 | 0.1 | 0.0 | -0.3 | 0.0 | 0.0 |
| Exchange rate | 1.0 | 0.6 | 0.2 | -0.2 | 0.2 | 0.0 | 0.6 |
| GDP at market prices | 314.4 | 1.2 | 0.8 | 0.4 | 0.7 | 0.0 | 3.1 |
| GDP at factor cost | 299.6 | 0.9 | 0.1 | 0.1 | 0.1 | 0.0 | 1.1 |
| Agrifood system | 90.6 | 2.7 | 0.2 | 0.2 | -0.1 | -0.3 | 2.7 |
| *Agriculture* | *40.4* | *4.4* | *-0.5* | *0.0* | *-0.3* | *-0.2* | *3.4* |
| *Off-farm* | *50.2* | *1.4* | *0.7* | *0.3* | *0.1* | *-0.4* | *2.1* |
| Non-agrifood system | 209.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.4 |
| Employment | 66.9 | 0.7 | 0.5 | 0.3 | 0.0 | -0.2 | 1.3 |
| Agrifood system | 38.0 | -0.1 | 0.2 | 0.2 | -0.3 | -0.4 | -0.3 |
| *Agriculture* | *26.9* | *-2.0* | *-0.8* | *-0.1* | *-0.6* | *-0.2* | *-3.5* |
| *Off-farm* | *11.1* | *4.6* | *2.5* | *0.9* | *0.6* | *-0.9* | *7.5* |
| Non-agrifood system | 28.9 | 1.7 | 1.0 | 0.4 | 0.5 | 0.1 | 3.4 |
| Kenya | | | | | | | |
| Consumer price index | 1.0 | 0.0 | 0.0 | -0.1 | -0.6 | 0.0 | -0.6 |
| Exchange rate | 1.0 | -0.7 | -0.4 | -0.6 | -0.6 | -0.1 | -3.2 |
| GDP at market prices | 93.4 | 2.0 | 1.4 | 0.4 | 1.0 | 0.0 | 4.9 |
| GDP at factor cost | 85.5 | 1.7 | 0.2 | 0.1 | 0.0 | 0.0 | 1.9 |
| Agrifood system | 29.1 | 4.9 | 0.4 | 0.4 | 0.0 | -0.2 | 5.3 |
| *Agriculture* | *19.7* | *6.2* | *0.0* | *0.1* | *-0.2* | *-0.3* | *5.8* |
| *Off-farm* | *9.4* | *2.1* | *1.3* | *0.9* | *0.4* | *0.0* | *4.5* |
| Non-agrifood system | 56.4 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 |
| Employment | 23.5 | 1.7 | 1.1 | 0.3 | 0.3 | -0.1 | 3.4 |
| Agrifood system | 14.1 | 1.7 | 0.9 | 0.3 | 0.3 | -0.3 | 3.5 |
| *Agriculture* | *12.5* | *1.0* | *0.5* | *0.1* | *0.2* | *-0.4* | *2.2* |
| *Off-farm* | *1.6* | *6.8* | *4.1* | *1.9* | *1.5* | *0.3* | *14.3* |
| Non-agrifood system | 9.4 | 1.7 | 1.4 | 0.2 | 0.2 | 0.1 | 3.3 |
| Nigeria | | | | | | | |
| Consumer price index | 1.0 | 0.2 | 0.3 | 0.0 | -0.4 | 0.0 | 0.1 |
| Exchange rate | 1.0 | 1.0 | 1.3 | 0.2 | 0.2 | 0.1 | 2.3 |
| GDP at market prices | 404.2 | 2.4 | 1.8 | 0.3 | 0.8 | 0.0 | 5.3 |
| GDP at factor cost | 400.2 | 2.0 | 0.1 | 0.1 | 0.0 | 0.0 | 2.0 |
| Agrifood system | 125.7 | 6.1 | -0.3 | 0.2 | -0.3 | -0.2 | 5.3 |
| *Agriculture* | *89.3* | *8.0* | *-1.2* | *0.2* | *-0.4* | *-0.3* | *6.3* |
| *Off-farm* | *37.4* | *1.7* | *1.8* | *0.0* | *-0.1* | *-0.1* | *3.2* |
| Non-agrifood system | 274.5 | 0.2 | 0.2 | 0.0 | 0.1 | 0.0 | 0.4 |
| Employment | 49.0 | 1.2 | 0.8 | 0.2 | 0.0 | -0.1 | 2.1 |
| Agrifood system | 22.8 | 0.6 | -0.5 | 0.3 | -0.2 | -0.4 | 0.0 |
| *Agriculture* | *18.1* | *-0.7* | *-2.3* | *0.2* | *-0.6* | *-0.5* | *-3.7* |
| *Off-farm* | *4.6* | *6.0* | *6.5* | *1.1* | *1.4* | *0.2* | *14.4* |
| Non-agrifood system | 26.3 | 1.7 | 2.0 | 0.2 | 0.2 | 0.1 | 3.9 |

**Source:** RIAPA model results
**Note:** Initial values for GDP are in billion USD, consumer price indices and exchange rates are normalized to 1, and employment is in millions of people.

Lastly, Table 3 reports employment changes. On average, labor contributes about 35 percent of factor incomes in the three case study countries, with the remainder coming from land and capital. Intuitively, the labor income and employment effects should depend on the cost structures and factor intensity of the stage in the food supply chain where the FLW reductions occur. For example, FLW reductions in the postharvest stage might be more capital-intensive as storage and cooling facilities are required, while those in the food services sectors might be more labor-intensive. Since we do not explicitly define the FLW technologies that result in these FLW reductions we also assume that the employment impacts are factor neutral.

Overall, FLW reductions are associated with an increase in employment as labor demand expands and more workers enter the labor force, i.e., from 1.3 percent in Bangladesh to 3.4 percent in Kenya. However, in both Bangladesh and Nigeria, agricultural employment declines across all scenarios, and by 3.5 and 3.7 percent in the combined scenario. Employment, therefore, increases only because of non-agricultural employment growth, particularly in the off-farm components of the agrifood system (e.g., in food processing and food trade and transport). In practice, such a positive employment outcome hinges on the ability of the off-farm components of the agrifood system to effectively absorb new labor market entrants and those workers released from the primary agricultural sector.

### 4.2 Household welfare impacts

Table 4 reports the effects on household real consumption spending and poverty. The combined scenario shows a substantial increase in consumption associated with the reduction in FLW. At the national level, households expand their consumption by between 4.7 and 7.0 percent across the three countries, at rates that far exceed the expansion in overall GDP at market prices. Both price and income effects explain this outcome. The increase in primary agricultural output raises producer incomes and lowers consumer prices, resulting in higher real consumption levels. Most of the gains in household consumption are associated with FLW reductions at the production and postharvest stages, which jointly account for about two-thirds of the increase in consumption. Reducing FLW at the distribution stage also strongly boosts consumption due to its direct and strong effect on food availability and consumer prices, as shown earlier in Table 3.

Results for rural and urban households are somewhat mixed, although in Bangladesh and Nigeria rural households experience larger increases in real consumption. This may reflect their closer ties to agrifood sectors. There is more conclusive evidence that real consumption levels of poor households grow faster than those of nonpoor households. Increased availability and lower prices of food will generally benefit poor households more given their larger food budget shares.

**Table 4. Welfare impacts: Real consumption and poverty**

| | Initial value | Scenario results: Deviation from initial value (percent or percentage-point) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Production | Post-harvest | Processing | Distribution | Consumption | Combined |
| *Real consumption (initial value in USD billions, changes in percent)* | | | | | | | |
| Bangladesh | | | | | | | |
| *National* | *202.8* | *1.8* | *1.1* | *0.6* | *1.1* | *0.1* | *4.7* |
| Rural | 128.2 | 1.8 | 1.1 | 0.6 | 1.2 | 0.1 | 4.8 |
| Urban | 74.6 | 1.8 | 1.0 | 0.5 | 1.0 | 0.1 | 4.5 |
| Poor | 34.5 | 2.1 | 1.3 | 0.7 | 1.3 | 0.0 | 5.3 |
| Non-poor | 168.2 | 1.8 | 1.0 | 0.5 | 1.1 | 0.1 | 4.5 |
| Kenya | | | | | | | |
| *National* | *72.5* | *2.2* | *1.5* | *0.4* | *1.2* | *0.0* | *5.4* |
| Rural | 28.6 | 2.3 | 1.3 | 0.3 | 0.9 | -0.2 | 5.0 |
| Urban | 43.9 | 2.1 | 1.6 | 0.4 | 1.3 | 0.2 | 5.6 |
| Poor | 8.7 | 3.2 | 2.0 | 0.4 | 1.4 | -0.2 | 7.3 |
| Non-poor | 63.8 | 2.1 | 1.4 | 0.4 | 1.1 | 0.1 | 5.1 |
| Nigeria | | | | | | | |
| *National* | *303.9* | *3.2* | *2.3* | *0.4* | *1.1* | *0.0* | *7.0* |
| Rural | 158.9 | 3.9 | 2.1 | 0.4 | 1.0 | -0.1 | 7.5 |
| Urban | 145.0 | 2.4 | 2.6 | 0.3 | 1.2 | 0.1 | 6.5 |
| Poor | 46.9 | 4.0 | 2.1 | 0.5 | 1.1 | -0.3 | 7.6 |
| Non-poor | 257.0 | 3.1 | 2.4 | 0.3 | 1.1 | 0.1 | 6.9 |
| *Poverty (initial value is the poverty headcount rate, changes in percentage-points)* | | | | | | | |
| Bangladesh | | | | | | | |
| *National* | *14.3* | *-1.0* | *-0.7* | *-0.3* | *-0.7* | *0.0* | *-2.5* |
| Urban | 10.9 | -0.8 | -0.6 | -0.3 | -0.5 | 0.0 | -1.8 |
| Rural | 15.6 | -1.1 | -0.8 | -0.4 | -0.7 | 0.0 | -2.8 |
| Kenya | | | | | | | |
| *National* | *36.8* | *-1.6* | *-0.9* | *-0.3* | *-0.7* | *0.0* | *-3.9* |
| Urban | 15.6 | -1.5 | -1.3 | -0.4 | -0.9 | -0.3 | -3.9 |
| Rural | 48.6 | -1.7 | -0.8 | -0.2 | -0.6 | 0.2 | -3.9 |
| Nigeria | | | | | | | |
| *National* | *39.1* | *-2.0* | *-0.9* | *-0.4* | *-0.7* | *0.1* | *-4.4* |
| Urban | 16.7 | -0.9 | -0.7 | -0.2 | -0.4 | 0.0 | -4.1 |
| Rural | 51.6 | -2.6 | -1.0 | -0.5 | -0.9 | 0.2 | -4.6 |

**Source:** RIAPA model results

Poverty results are reported in the bottom half of Table 4. In absolute (percentage-point) terms, in the combined scenario, poverty rates fall faster in Kenya and Nigeria than in Bangladesh. The percentage-point decline in poverty is also generally larger in rural areas. Reductions in poverty are highest in the production stage, especially for rural households, while urban households experience relatively sharp reductions in poverty when FLW is reduced in the off-farm stages. Poverty changes are negligible in the consumption stage as the benefits from reducing food waste appear to be offset by the negative impacts of reduced food demand on farm household incomes.

**Table 5. Food security impacts: Diet deprivation and undernourishment**

| | | Scenario results: Deviation from initial value (point change or percentage-point) | | | | | |
|---|---|---|---|---|---|---|---|
| | Initial value | Production stage | Post-harvest stage | Processing stage | Distribution stage | Consumption stage | All stages combined |
| *Diet deprivation (initial value is an index value, changes are point changes in the index)* | | | | | | | |
| Bangladesh | | | | | | | |
| *National* | *40.8* | *-1.1* | *-0.5* | *-0.1* | *-0.7* | *-0.1* | *-2.5* |
| Urban | 39.3 | -1.1 | -0.6 | -0.2 | -0.7 | -0.1 | -2.6 |
| Rural | 41.4 | -1.1 | -0.5 | -0.1 | -0.7 | -0.1 | -2.5 |
| Kenya | | | | | | | |
| *National* | *42.2* | *-3.0* | *-1.8* | *-0.3* | *-2.0* | *-0.1* | *-6.9* |
| Urban | 32.9 | -2.7 | -2.2 | -0.3 | -2.3 | -0.1 | -7.2 |
| Rural | 47.4 | -3.2 | -1.6 | -0.2 | -1.8 | 0.0 | -6.7 |
| Nigeria | | | | | | | |
| *National* | *49.4* | *-2.3* | *-1.2* | *-0.2* | *-1.6* | *0.0* | *-5.5* |
| Urban | 43.2 | -2.6 | -1.9 | -0.2 | -2.1 | -0.1 | -6.9 |
| Rural | 52.8 | -2.2 | -0.8 | -0.2 | -1.3 | 0.0 | -4.6 |
| *Undernourishment (initial value is a prevalence rate, changes in percentage-points)* | | | | | | | |
| Bangladesh | | | | | | | |
| *National* | *9.7* | *-0.9* | *-0.8* | *-0.6* | *-0.4* | *0.0* | *-2.7* |
| Urban | 11.5 | -1.2 | -1.1 | -0.8 | -0.6 | 0.0 | -3.4 |
| Rural | 9.1 | -0.7 | -0.7 | -0.5 | -0.4 | 0.0 | -2.5 |
| Kenya | | | | | | | |
| *National* | *24.8* | *-1.3* | *-1.0* | *-0.3* | *-0.4* | *0.0* | *-2.9* |
| Urban | 15.4 | -1.1 | -0.9 | -0.2 | -0.5 | -0.1 | -2.8 |
| Rural | 30.0 | -1.4 | -1.0 | -0.3 | -0.4 | 0.0 | -3.0 |
| Nigeria | | | | | | | |
| *National* | *14.6* | *-2.5* | *-1.6* | *-0.6* | *-0.7* | *-0.1* | *-4.2* |
| Urban | 10.0 | -1.3 | -1.3 | -0.7 | -0.8 | -0.3 | -2.8 |
| Rural | 17.2 | -3.2 | -1.7 | -0.5 | -0.6 | 0.0 | -4.9 |

**Source:** RIAPA model results

Table 5 presents food security results from the diet quality and hunger modules. As explained in Section 3.1, diet deprivation is measured by the ReDD, a multidimensional indicator of diet quality, while the hunger module measures the share of people that are undernourished. A decline in ReDD is associated either with a decline in the number of food groups in which households are deprived or a decline in food consumption shortfalls. We interpret such a decline as an improvement in diet quality. In the combined scenario, ReDD declines by 2.5 points in Bangladesh, by 6.9 points in Kenya, and by 5.4 points in Nigeria. The effects are stronger when FLW is reduced at the production and postharvest stages. The distribution stage is also relatively important for diet quality as it contributes to more diverse foods becoming available for final consumption. However, reducing food waste at the consumption stage itself does not significantly improve diet quality.

The bottom section of the table reports changes in undernourishment. The baseline estimates of undernourishment are consistent with those of the FAO (FAO, 2022b) and range from 9.7 percent in Bangladesh to 24.8 percent in Kenya. FLW reductions cause marked declines in the proportion of undernourished people, with rural populations in Kenya and Nigeria and urban populations in Bangladesh experiencing the largest reductions in undernourishment, mirroring the changes in poverty. Halving FLW lifts over 14 million people above the calorie threshold, with over 60 percent of those people living in rural areas.

# 5 CONCLUSIONS

Food loss and waste (FLW) along food supply and consumption chains are estimated to account for up to one-third of food produced for human consumption globally. Baseline estimates of FLW presented in this paper reveal that Nigeria loses over 32.8 percent (69.2 million tons), Kenya 27.6 percent (9.2 million tons), and Bangladesh 19.4 percent (21.2 million tons) of primary equivalent food supply each year. These losses point to significant inefficiencies in food supply chains and highlight concerns about their environmental sustainability. FLW further contributes to undernourishment, poor diet quality, and poor health of populations. While reducing FLW is not a panacea for addressing inefficiencies, environmental sustainability, and diet-related health concerns, it certainly deserves close consideration. Although the SDGs have brought the issue of FLW reductions to the fore, there have been limited attempts to quantify the economywide benefits of reducing FLW.

This study partially fills that gap by employing general equilibrium models to examine the direct and indirect effects of halving FLW separately within and simultaneously across all stages of all food supply and consumption chains in Bangladesh, Kenya, and Nigeria. An economywide perspective is important since linkages across food value chains and across the different stages within food supply and consumption chains mean policy interventions in one stage may have implications also for others.

Our model results highlight the significant socioeconomic gains that can be realized from reducing FLW. FLW reductions raise GDP at market prices by between 3.1 in Bangladesh and 5.3 percent in Nigeria. Gains in GDP at factor cost are slightly lower, ranging from 1.1 to 2 percent. The biggest gains in GDP are recorded in the production and postharvest stages. Even though the agricultural sector sheds workers as the sector becomes more productive, strong employment demand in the off-farm components of the agrifood system, such as food processing and trade and transport, causes overall labor force participation and employment to increase in all case study countries. FLW reductions have small but ambiguous effects on consumer prices. Whereas FLW reductions on farms cause prices to decline due to increased productivity and food supply, FLW reductions in the processing or consumption stages lead to lower demand and hence higher prices.

Households experience significant gains from FLW reductions, although most of those gains originate from FLW reductions at the production and postharvest stages rather than the consumption stage. Overall, real household consumption increases by 4.7 to 7.0 percent across the three countries, while poverty declines by between 2.5 and 4.4 percentage points, with slightly higher declines in rural areas. Declines in the prevalence of undernutrition largely mirror changes in poverty. We also measure significant declines in diet deprivation, which reflects an improvement in diet quality as household diets move closer to an ideal, healthy reference diet.

In conclusion, the significant economywide gains seen here provide a strong justification for adopting FLW reduction strategies. However, there are three caveats to this modeling exercise. First, this study uses global FLW data which may lack the accuracy and precision of country-specific survey data. To gain a better understanding of the magnitude of the issue, it is necessary to collect data on FLW from various sources, such as farmers, distributors, retailers, and consumers. This will provide a more accurate baseline. Second, our results are sensitive to baseline estimates of FLW. The challenges associated with accurately measuring losses along and across food value chains are well-documented (Parfitt, et al., 2021;

Xue, et al., 2017). Third, the model is not currently equipped to measure the environmental or other social benefits of more sustainable use of natural resources or reduced emissions; thus, while we measure the economywide benefits, we potentially understate the environmental benefits. Fourth, we do not incorporate the costs of policies or investments required to achieve FLW reductions. Food can be lost or wasted due to a variety of issues, such as inadequate infrastructure, outdated technologies, market inefficiencies, and consumer behavior. Fixing these problems can be a costly engagement and typically requires additional resources, including labor, and raises production costs. This implies our estimates of economic benefits are potentially overstated. Quantifying such costs remained challenging because of the complex mix of technologies that can (or should be) adopted and the behavioral changes that are required to reduce FLW (Cattaneo, et al., 2021; Rosegrant, et al., 2015). Obtaining more accurate FLW estimates, accounting for positive environmental externalities, and costing the policy and investment options needed to reduce FLW and incorporating these into the model are all important areas for future research.

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# 7 APPENDIX

## 7.1 Food groups and baseline food loss and waste percentages

**Table A1. Food groups in the FAO Food Balance Sheets**

| Food group | Individual food items |
|---|---|
| Cereals and cereal products (excluding cereals-based alcoholic beverages) | Wheat, rice (milled), barley, maize, rye, oats, millet, sorghum, other cereals |
| Roots and tubers | Potatoes, sweet potatoes, cassava, yams, other roots |
| Oilseeds and pulses (including nuts) | Soybeans, groundnuts (shelled), sunflower seeds, rape and mustard seed, cottonseed, coconuts, sesame seed, palm kernels, olives, other oil crops |
| Fruits and vegetables (including bananas, excluding fruit-based alcoholic beverages) | Oranges and mandarins, lemons and limes, grapefruit, other citrus, bananas, plantains, apples, pineapples, dates, grapes, other fruit, tomatoes, onions, other vegetables |
| Meat products | Bovine meat, goat meat, pig meat, poultry meat, other meat, offal |
| Fish and seafood | Freshwater fish, demersal fish, pelagic fish, other marine fish, crustaceans, cephalopods, other aquatic products, aquatic mammal meat, other aquatic animals, aquatic plants |
| Dairy products | Milk |
| Other foods | Sugar, tea, coffee, ginger, piper, other species, other cash crops |

**Source:** Authors

**Table A2. Average food loss and waste percentages by food supply chain stage and food group**

| | Production | Post-harvest | Processing | Distribution (fresh) | Distribution (processed) | Consump-tion |
|---|---|---|---|---|---|---|
| Sub-Saharan Africa | | | | | | |
| Cereals | 6.0 | 8.0 | 3.5 | 2.0 | 1.0 | 1.0 |
| Roots & tubers | 14.0 | 18.0 | 15.0 | 5.0 | 2.5 | 2.0 |
| Oilseeds & pulses | 12.0 | 8.0 | 8.0 | 2.0 | 1.0 | 1.0 |
| Fruits & vegetables | 10.0 | 9.0 | 25.0 | 17.0 | 8.5 | 5.0 |
| Meat products | 15.0 | 0.7 | 5.0 | 7.0 | 3.5 | 2.0 |
| Fish & seafood | 5.7 | 6.0 | 9.0 | 15.0 | 7.5 | 2.0 |
| Dairy products | 6.0 | 11.0 | 0.1 | 10.0 | 5.0 | 0.1 |
| Other foods | 12.0 | 8.0 | 8.0 | 2.0 | 1.0 | 1.0 |
| South and South-East Asia | | | | | | |
| Cereals | 6.0 | 7.0 | 3.5 | 2.0 | 1.0 | 3.0 |
| Roots & tubers | 6.0 | 19.0 | 10.0 | 11.0 | 5.5 | 3.0 |
| Oilseeds & pulses | 7.0 | 12.0 | 8.0 | 2.0 | 1.0 | 1.0 |
| Fruits & vegetables | 15.0 | 9.0 | 25.0 | 10.0 | 5.0 | 7.0 |
| Meat products | 5.1 | 0.3 | 5.0 | 7.0 | 3.5 | 4.0 |
| Fish & seafood | 5.7 | 6.0 | 9.0 | 15.0 | 7.5 | 2.0 |
| Dairy products | 8.2 | 6.0 | 2.0 | 10.0 | 5.0 | 1.0 |
| Other foods | 7.6 | 8.5 | 8.9 | 8.1 | 4.1 | 3.0 |

**Source:** Based on Gustavsson et al. (2011)
**Note:** The percentage loss reported for “Other foods” is an average of losses in the foods not elsewhere defined. Percentage losses for processed distribution are assumed to be half that of fresh distribution.

## 7.2 Selected model equations and simulation parameters

A detailed description of the CGE model with mathematical equations is presented in Lofgren et al. (2011). In this technical appendix we highlight those equations in the production, trade, and institution blocks of the model code that were adapted to accommodate the FLW reduction scenarios described in Section 3. The equations highlighted here follow the production stage and commodity flows presented in Figure 2, which also reference the variable names used below for ease of reference.

*Production scenario*: Each producer, represented by an activity, $a$, maximizes profits subject to a two-tier production system. At the top tier, activity output ($QA_a$) is a Leontief function that combines aggregate intermediate inputs ($QINTA_a$) and value added ($QVA_a$) in fixed proportions. At the second tier, value added is a CES function of factors of production ($QF_f$), where factors, *f*, may include multiple types of labor, capital, or land. The value-added function is shown in Equation 1a, with $\alpha_a^{va}$ the efficiency parameter, $\delta_{f,a}^{va}$ a share parameter for factor *f* in activity *a*, and $\rho_a^{va}$ the CES function exponent. The right-hand side of the equation shows how value added is a fixed share ($iva_a$) of activity output.

$$QVA_a = PRD\_TFP_{a^f}.\alpha_a^{va}.\left(\sum_f \delta_{f,a}^{va}.QF_{f,a}{}^{-\rho_a^{val}}\right)^{-\frac{1}{\rho_a^{va}}} = iva_a.QA_a \qquad (1a)$$

The production scenario entails an efficiency increase in the use of factors of production and intermediate inputs. Parameter $PRD\_TFP_{a^f}$ adjusts the CES efficiency parameter in the value-added function, which raises total factor productivity and hence the value added per unit of primary input. We simultaneously reduce the quantity of aggregate intermediate input required per unit of farm output by a factor $PRD\_INT_{a^f}$ as shown in Equation 1b. This adjustment factor is proportionate to the efficiency gain factor in the CES function and accounts for increased intermediate input use efficiency. Since the production stage entails FLW reductions on the farm only, the gains apply to the subset of agricultural activities that produce food ($a^f \in a$).

$$QINTA_a = inta_a.PRD\_INT_{a^f}.QA_a \qquad (1b)$$

*Postharvest scenario*: Agricultural activity outputs ($QA_a$) are either consumed by farm households themselves (home consumption) or marketed. Equation 2a shows how output is allocated in fixed proportions ($\theta_{a,c}$) across $QHA_{a,c,h}$, the quantity of home consumption of commodity *c* produced by activity *a*, for household *h*, and $QXAC_{a,c}$, the quantity of marketed output of commodity *c* from activity *a*.

$$QXAC_{a,c} + \sum_h QHA_{a,c,h} = \theta_{a,c}.QA_a \qquad (2a)$$

Since productive activities can produce multiple commodities, marketed output is aggregated across activities using a CES aggregation function shown in Equation 2b. $\alpha_c^{ac}$, $\delta_{a,c}^{ac}$, and $\rho_c^{ac}$ are the shift, share, and function exponent parameters, respectively, while $QX_c$ represents the aggregated marketed quantity of domestic output of each commodity.

$$QX_c = \alpha_c^{ac}.\left(\sum_a \delta_{a,c}^{ac}.QXAC_{a,c}{}^{-\rho_c^{ac}}\right)^{-\frac{1}{\rho_c^{ac}-1}} \qquad (2b)$$

Marketed commodity output is supplied to either domestic ($QD_c$) or export ($QE_c$) markets as governed by the CET output transformation function in Equation 2c. Once again, $\alpha_c^t$, $\delta_c^t$, and $\rho_c^t$ are the shift, share, and function exponent parameters. For the postharvest scenario we introduce an adjustment factor, $PST_{c^f \in c}$, which adjusts the shift parameter so that the quantity of commodities in domestic and export markets per unit of activity output is increased. These gains apply to the subset of primary and processed food commodities, $c^f \in c$.

$$QX_c = PST_{c^f}.\alpha_c^t.\left(\delta_c^t.QE_c{}^{\rho_c^t} + (1-\delta_c^{otr}).QD_c{}^{\rho_c^t}\right)^{\frac{1}{\rho_c^t}} \tag{2c}$$

*Processing scenario*: The disaggregated intermediate input demand function in Equation 3 is part of the second tier of the production system described earlier. It specifies the fixed proportions (Leontief specification) of intermediate inputs ($QINT_{c,a}$) used in the formation of aggregate intermediate inputs ($QINTA_a$) (compare Equation 1b). In this scenario we lower the input-output coefficients ($ica_{c,a}$) for food inputs by a factor $PRC_{c^f}$ to reflect reduced waste and hence more efficient use of these inputs. As before, $c^f \in c$ is the subset of primary and processed food commodities, but no restriction is placed on activities ($a$), i.e., any processor that uses primary or processed food commodities as intermediate inputs, including producers of nonfood products, experience this efficiency gain.

$$QINT_{c,a} = ica_{c,a}.PRC_{c^f}.QINTA_a \tag{3}$$

*Distribution scenario*: The composite supply function in Equation 4 captures imperfect substitutability between imported ($QM_c$) and domestically produced ($QD_c$) goods via a CES function that forms a composite commodity ($QQ_c$) which constitutes the quantity of goods supplied to the domestic market. $\alpha_c^q$, $\delta_c^q$, and $\rho_c^q$ are the shift, share, and function exponent parameters. Parameter $DST_{c^f}$ adjusts the shift parameter for food commodities ($c^f \in c$) so that the composite food commodity available for domestic consumption increases per unit of imports and domestic supply.

$$QQ_c = DST_{c^f}.\alpha_c^q.\left(\delta_c^q.QM_c{}^{-\rho_c^q} + (1-\delta_c^{com}).QD_c{}^{-\rho_c^q}\right)^{-\frac{1}{\rho_c^q}} \tag{4}$$

*Consumption scenario:* Household consumption is modeled using a Linear Expenditure System (LES). Separate equations are required to model demand for marketed (Equation 5a) and home-produced goods (Equation 5b). Households must first satisfy subsistence consumption of marketed or home-produced goods, with parameters $\gamma_{c,h}^m$ and $\gamma_{a,c,h}^h$ representing fixed consumption quantities that are valued at market ($PQ_c$) or producer prices ($PXAC_{a,c}$). Subsistence consumption expenditure is subtracted from disposable household income ($EH_h$) and the balance – also called supernumerary income – is spent on goods according to fixed marginal budget shares, $\beta_{c,h}^m$ and $\beta_{c,h}^h$. In this scenario the marginal budget shares and quantity of subsistence consumption of food commodities ($c^f \in c$) are lowered by a factor $CON_{c^f,h^n}$ to reflect reduced food waste by households. This results in lower consumption expenditure on marketed ($PQ_c.QH_{c,h}$) or home-produced food ($PXAC_{a,c}.QHA_{a,c,h}$). The demand reductions are only applied on nonpoor households in the third through fifth expenditure quintiles ($h^n \in h$) under the assumption that poor households do not waste food.

$$PQ_c.QH_{c,h} = PQ_c.CON_{c^f,h^n}.\gamma_{c,h}^m + CON_{c^f,h^n}.\beta_{c,h}^m.\left(EH_h - \sum_c PQ_c.CON_{c^f,h^n}.\gamma_{c,h}^m - \sum_a \sum_c PXAC_{a,c}.CON_{c^f,h^n}.\gamma_{a,c,h}^m\right) \tag{5a}$$

$$PXAC_{a,c}.QHA_{a,c,h} = PXAC_{a,c}.CON_{c^f,h^n}.\gamma_{a,c,h}^h + CON_{c^f,h^n}.\beta_{c,h}^h.\ \left(EH_h - \sum_c PQ_c.CON_{c^f,h^n}.\gamma_{c,h}^h - \sum_a \sum_c PXAC_{a,c}.CON_{c^f,h^n}.\gamma_{a,c,h}^h\right) \tag{5b}$$

Even though savings on food can be used by households to buy more goods and services, including food, the net effect is a reduction in food demand. However, since less food is wasted, households increase their food intake, resulting in welfare improvements. This is factored into the microsimulation model in that poverty, diet quality, and hunger results are based on a real consumption expenditure measure ($REXP_{c,h}$). This measure is obtained by dividing the simulated consumption quantities ($QH^{*}_{c,h}$ and $QHA^{*}_{a,c,h}$) by the adjustment factor in Equations 5a and 5b ($CON_{c^f,h^n}$), which represents the food quantities ingested when FLW is halved, and multiplying these by initial (baseline) prices ($\overline{PQ}_c$ and $\overline{PXAC}_{a,c}$). The poverty measure is based on changes in real expenditure across all commodities, while the food security measures only consider changes in real expenditure on food items.

$$REXP_{c,h} = \overline{PQ}_c . QH^{*}_{c,h}/CON_{c^f,h^n} + \overline{PXAC}_{a,c} . QHA^{*}_{a,c,h}/CON_{c^f,h^n} \qquad (5c)$$

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