Balancing People, Planet, and Profit in Urban Food Waste Management

Supplementary Materials

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List of Appendices

Appendix 1. Model Equations, Data Points, and Assumptions

The food waste dynamics model was first developed to simulate the urban food waste impacts on food, energy, water and climate (FEWC) nexus in the case of Bristol city, UK (Parsa et al., 2023).The model is now expanded to explore the socio-economic impacts of food waste management as well. This document reports the variables, parameters and equations of both studies. The data is divded into 16 tables (Tables A1.1 to A1.16) for enhanced readability. The following equation and data tables are sufficient to replicate and reproduce the environmental and socio-economic model and the findings reported in both studies.

The model is developed in Stella Architect (isee systems, 2019) and uses Euler Integration method to explore the system behavior for 12 years (STARTTIME=0, STOPTIME=12, and DT=0.25). Overall, the model has 517 (618) variables (i.e., array expansion in parentheses), including 14 (22) Stocks, 50 (58) Flows, and 453 (538) Converters. Excluding the Stocks, 181 (224) variables are Constants, 2 (2) are Graphical, and 322 (372) varioables are defined by Equations.

Following tables (Tables A1.1 to A1.16) provide the full list of equations, parameter values, data sources, and assumptions of the model.

Table A1.1. Array Variables and Dimensions

ARRAY DIMENSIONS	SUBSCRIPT NAMES
ENERGY_CONSUMPTION_OF_UK_HOUSEHOLD_FOOD[Fuels]	Fuels = Electricity,Natural_Gas, Oil,Solid_Fuels
energy_use_per_tonne_of_household_food[Fuels]	
household_energy_consumption[Fuels]	
HOUSEHOLD_ENERGY_COST_PER_MWH[Fuels]	
AVERAGE_CONSUMPTION_PER_BUSINESS[HaFs_businesses]	HaFs_businesses = Restaurants,Pubs,Education,Healthcare,Hotels, Quick_Service,Services, Leisure,Others
AVERAGE_PURCHASE_PER_BUSINESS[HaFs_businesses]	
HaFS_growth[HaFs_businesses]	
Urban_HaFS_Businesses[HaFs_businesses]	

Table A1.2. Primary Production Food, Surplus, and Waste Equations

EQUATION	UNIT
initial_production_waste = INIT(Primary_Production*PRODUCTION_WASTE_FRACTION)	Tonne/ Year
Primary_Production(t) = Primary_Production(t - dt) + (primary_production_rate - production_local_supply - production_surplus - production_to_manufacture - production_waste_rate) * dt	Tonne
INFLOWS:	
primary_production_rate = production_shortfall+production_expected_outflow	Tonne/ Year
OUTFLOWS:	
production_local_supply = urban_farming_to_household+urban_farming_to_HaFS	Tonne/ Year
production_surplus = production_total_to_animal_feed+production_total_redistribution	Tonne/ Year
production_waste_rate = Primary_Production*PRODUCTION_WASTE_FRACTION-	Tonne/ Year

production_waste_reduction-production_redistribution_change-production_to_animal_feed_change	
production_expected_outflow = production_surplus+production_local_supply+production_to_manufacture+production_waste_rate	Tonne/ Year
production_demand = production_to_manufacture+ INIT(production_surplus)+INIT(production_waste_rate)+production_local_supply -production_waste_reduction	Tonne/ Year
production_redistribution_change = initial_production_waste*RAMP(PRODUCTION_REDISTRIBUTION_CHANGE_FRACTION/100)	Tonne/ Year
production_shortfall = production_demand-Primary_Production/STOCK_ADJUSTMENT_TIME	Tonne/ Year
production_to_AD_change = initial_production_waste*RAMP(PRODUCTION_TO_AD_CHANGE_FRACTION/100)	Tonne/ Year
production_to_animal_feed_change = initial_production_waste*RAMP(PRODUCTION_TO_ANIMAL_FEED_CHANGE_FRACTION/100)	Tonne/ Year
production_to_compost_change = initial_production_waste*RAMP(PRODUCTION_TO_COMPOST_CHANGE_FRACTION/100)	Tonne/ Year
production_to_incineration_change = initial_production_waste*RAMP(PRODUCTION_TO_INCINERATION_CHANGE_FRACTION/100)	Tonne/ Year
production_to_landfill_change = initial_production_waste*RAMP(PRODUCTION_TO_LANDFILL_CHANGE_FRACTION/100)	Tonne/ Year
production_total_redistribution = production_redistribution_change+PRODUCTION_INITIAL_REDISTRIBUTION	Tonne/ Year
production_total_to_animal_feed = production_to_animal_feed_change+PRODUCTION_INITIAL_TO_ANIMAL_FEED	Tonne/ Year
Production_Waste(t) = Production_Waste(t - dt) + (production_waste_rate - production_to_landfill - production_to_incineration - production_to_AD - production_to_compost) * dt	Tonne

INFLOWS:	
production_waste_rate = Primary_Production*PRODUCTION_WASTE_FRACTION-production_waste_reduction-production_redistribution_change-production_to_animal_feed_change	Tonne/Year
OUTFLOWS:	
production_to_landfill = Production_Waste*PRODUCTION_TO_LANDFILL_FRACTION+production_to_landfill_change	Tonne/Year
production_to_incineration = Production_Waste*PRODUCTION_TO_INCINERATION_FRACTION+production_to_incineration_change	Tonne/Year
production_to_AD = Production_Waste*PRODUCTION_TO_AD_FRACTION+production_to_AD_change	Tonne/Year
production_to_compost = Production_Waste *PRODUCTION_TO_COMPOST_FRACTION +production_to_compost_change	Tonne/Year
production_waste_reduction = initial_production_waste*RAMP(PRODUCTION_REDUCTION_CHANGE_FRACTION/100)	Tonne/Year

Table A1.3. Manufacture Food, Surplus, and Waste Equations

EQUATION	**UNIT**
initial_manufacture_waste = INIT(Manufacture_Inventory*MANUFACTURE_WASTE_FRACTION)	Tonne/Year
Manufacture_Inventory(t) = Manufacture_Inventory(t - dt) + (production_to_manufacture - manufacture_waste_rate - manufacture_to_retail - manufacture_surplus) * dt	Tonne
INFLOWS:	
production_to_manufacture = manufacture_shortfall+manufacture_expected_outflow	Tonne/Year
OUTFLOWS:	

manufacture_waste_rate = Manufacture_Inventory*MANUFACTURE_WASTE_FRACTION-manufacture_waste_reduction-manufacture_to_redistribution_change-manufacture_to_animal_feed_change	Tonne/ Year
manufacture_surplus = manufacture_total_redistribution+manufacture_total_to_animal_feed	Tonne/ Year
manufacture_expected_outflow = manufacture_to_retail+manufacture_surplus+manufacture_waste_rate	Tonne/ Year
manufacture_demand = manufacture_to_retail+INIT(manufacture_waste_rate)+INIT(manufacture_surplus)	Tonne/ Year
manufacture_shortfall = manufacture_demand-Manufacture_Inventory/STOCK_ADJUSTMENT_TIME	Tonne/ Year
manufacture_to_AD_change = RAMP(MANUFACTURE_TO_AD_CHANGE_FRACTION/100)*initial_manufacture_waste	Tonne/ Year
manufacture_to_animal_feed_change = RAMP(MANUFACTURE_TO_ANIMAL_FEED_CHANGE_FRACTION/100)*initial_manufacture_waste	Tonne/ Year
manufacture_to_compost_change = RAMP(MANUFACTURE_TO_COMPOST_CHANGE_FRACTION/100)*initial_manufacture_waste	Tonne/ Year
manufacture_to_incineration_change = RAMP(MANUFACTURE_TO_INCINERATION_CHANGE_FRACTION/100)*initial_manufacture_waste	Tonne/ Year
manufacture_to_landfill_change = RAMP(MANUFACTURE_TO_LANDFILL_CHANGE_FRACTION/100)*initial_manufacture_waste	Tonne/ Year
manufacture_to_redistribution_change = MIN(MANUFACTURE_EDIBLE_SURPLUS_FRACTION*initial_manufacture_waste, RAMP(MANUFACTURE_TO_REDISTRIBUTION_CHANGE_FRACTION/100)*initial_manufacture_waste)	Tonne/ Year
manufacture_total_redistribution = MANUFACTURE_INITIAL_REDISTRIBUTION+manufacture_to_redistribution_change	Tonne/ Year

manufacture_total_to_animal_feed = MANUFACTURE_INITIAL_TO_ANIMAL_FEED+manufacture_to_animal_feed_change	Tonne/ Year
Manufacture_Waste(t) = Manufacture_Waste(t - dt) + (manufacture_waste_rate - manufacture_to_AD - manufacture_to_incineration - manufacture_to_compost - manufacture_to_landfill) * dt	Tonne
INFLOWS:	
manufacture_waste_rate = Manufacture_Inventory*MANUFACTURE_WASTE_FRACTION-manufacture_waste_reduction-manufacture_to_redistribution_change-manufacture_to_animal_feed_change	Tonne/ Year
OUTFLOWS:	
manufacture_to_AD = MANUFACTURE_TO_AD_FRACTION*Manufacture_Waste+manufacture_to_AD_change	Tonne/ Year
manufacture_to_incineration = Manufacture_Waste*MANUFACTURE_TO_INCINERATION_FRACTION+manufacture_to_incineration_change	Tonne/ Year
manufacture_to_compost = MANUFACTURE_TO_COMPOST_FRACTION*Manufacture_Waste+manufacture_to_compost_change	Tonne/ Year
manufacture_to_landfill = Manufacture_Waste*MANUFACTURE_TO_LANDFILL_FRACTION+manufacture_to_landfill_change	Tonne/ Year
manufacture_waste_reduction = initial_manufacture_waste*RAMP(MANUFACTURE_REDUCTION_FRACTION/100)	Tonne/ Year

Table A1.4. Retail Food, Surplus, and Waste Equations

EQUATION	**UNIT**
initial_retail_waste = INIT(Retail_Inventory*RETAIL_WASTE_FRACTION)	Tonne/ Year

Retail_Inventory(t) = Retail_Inventory(t - dt) + (manufacture_to_retail - retail_waste_rate - retail_to_consumer - retail_surplus) * dt	Tonne
INFLOWS:	
manufacture_to_retail = retail_shortfall+retail_expected_outflow	Tonne/ Year
OUTFLOWS:	
retail_waste_rate = Retail_Inventory*RETAIL_WASTE_FRACTION-retail_waste_reduction-retail_to_redistribution_change-retail_to_animal_feed_change	Tonne/ Year
retail_to_consumer = HaFS_purchase+household_purchase	Tonne/ Year
retail_surplus = retail_total_to_animal_feed+retail_total_redistribution	Tonne/ Year
retail_expected_outflow = retail_to_consumer+retail_surplus+retail_waste_rate	Tonne/ Year
retail_demand = retail_to_consumer+INIT(retail_surplus)+INIT(retail_waste_rate)	Tonne/ Year
retail_shortfall = retail_demand-Retail_Inventory/STOCK_ADJUSTMENT_TIME	Tonne/ Year
retail_to_AD_change = RAMP(RETAIL_TO_AD_CHANGE_FRACTION/100)*initial_retail_waste	Tonne/ Year
retail_to_animal_feed_change = RAMP(RETAIL_TO_ANIMAL_FEED_CHANGE_FRACTION/100)*initial_retail_waste	Tonne/ Year
retail_to_compost_change = RAMP(RETAIL_TO_COMPOST_CHANGE_FRACTION/100)*initial_retail_waste	Tonne/ Year
retail_to_incineration_change = RAMP(RETAIL_TO_INCINERATION_CHANGE_FRACTION/100)*initial_retail_waste	Tonne/ Year
retail_to_landfill_change = RAMP(RETAIL_TO_LANDFILL_CHANGE_FRACTION/100)*initial_retail_waste	Tonne/ Year
retail_to_redistribution_change = MIN(RETAIL_EDIBLE_SURPLUS_FRACTION*initial_retail_waste,	Tonne/ Year

RAMP(RETAIL_TO_REDISTRIBUTION_CHANGE_FRACTION/100)*initial_retail_waste)	
retail_total_redistribution = retail_to_redistribution_change+RETAIL_INITIAL_REDISTRIBUTION	Tonne/Year
retail_total_to_animal_feed = retail_to_animal_feed_change+RETAIL_INITIAL_TO_ANIMAL_FEED	Tonne/Year
Retail_Waste(t) = Retail_Waste(t - dt) + (retail_waste_rate - retail_to_AD - retail_to_incineration - retail_to_compost - retail_to_landfill) * dt	Tonne
INFLOWS:	
retail_waste_rate = Retail_Inventory*RETAIL_WASTE_FRACTION-retail_waste_reduction-retail_to_redistribution_change-retail_to_animal_feed_change	Tonne/Year
OUTFLOWS:	
retail_to_AD = RETAIL_TO_AD_FRACTION*Retail_Waste+retail_to_AD_change	Tonne/Year
retail_to_incineration = Retail_Waste*RETAIL_TO_INCINERATION_FRACTION+retail_to_incineration_change	Tonne/Year
retail_to_compost = retail_to_compost_change+RETAIL_TO_COMPOST_FRACTION*Retail_Waste	Tonne/Year
retail_to_landfill = Retail_Waste*RETAIL_TO_LANDFILL_FRACTION+retail_to_landfill_change	Tonne/Year
retail_waste_reduction = initial_retail_waste*RAMP(RETAIL_REDUCTION_FRACTION/100)	Tonne/Year

Table A1.5. HaFS Food, Surplus, and Waste Equations

EQUATION	**UNIT**
HaFS_Food(t) = HaFS_Food(t - dt) + (HaFS_from_farm + HaFS_purchase - HaFS_waste_rate - HaFS_surplus - HaFS_consumption) * dt	Tonne
INFLOWS:	
HaFS_from_farm = urban_farming_to_HaFS	Tonne/Year

HaFS_purchase = hafs_shortfall+hafs_expected_outflow	Tonne/ Year
OUTFLOWS:	
HaFS_waste_rate = HAFS_WASTE_FRACTION*HaFS_Food-HaFS_waste_reduction-HaFS_to_redistribution_change	Tonne/ Year
HaFS_surplus = HaFS_total_redistribution	Tonne/ Year
HaFS_consumption = SUM(Urban_HaFS_Businesses*AVERAGE_CONSUMPTION_PER_BUSINESS)	Tonne/ Year
hafs_expected_outflow = HaFS_consumption+HaFS_waste_rate+HaFS_surplus	Tonne/ Year
HaFS_food_demand = SUM(Urban_HaFS_Businesses*AVERAGE_PURCHASE_PER_BUSINESS)	Tonne/ Year
hafs_shortfall = HaFS_food_demand-HaFS_Food/STOCK_ADJUSTMENT_TIME-HaFS_from_farm	Tonne/ Year
HaFS_to_AD_change = RAMP(HAFS_TO_AD_CHANGE_FRACTION/100)*initial_HaFS_waste	Tonne/ Year
HaFS_to_compost_change = RAMP(HAFS_TO_COMPOST_CHANGE_FRACTION/100)*initial_HaFS_waste	Tonne/ Year
HaFS_to_incineration_change = RAMP(HAFS_TO_INCINERATION_CHANGE_FRACTION/100)*initial_HaFS_waste	Tonne/ Year
HaFS_to_landfill_change = RAMP(HAFS_TO_LANDFILL_CHANGE_FRACTION/100)*initial_HaFS_waste	Tonne/ Year
HaFS_to_redistribution_change = RAMP(HAFS_TO_REDISTRIBUTION_CHANGE_FRACTION/100)*initial_HaFS_waste	Tonne/ Year
HaFS_total_redistribution = HaFS_to_redistribution_change+HAFS_INITIAL_REDISTRIBUTION	Tonne/ Year
HaFS_Waste(t) = HaFS_Waste(t - dt) + (HaFS_waste_rate - HaFS_to_AD - HaFS_to_compost - HaFS_to_landfill - HaFS_to_incineration) * dt	Tonne
INFLOWS:	
HaFS_waste_rate = HAFS_WASTE_FRACTION*HaFS_Food-HaFS_waste_reduction-HaFS_to_redistribution_change	Tonne/ Year
OUTFLOWS:	

HaFS_to_AD = HAFS_TO_AD_FRACTION*HaFS_Waste+HaFS_to_AD_change	Tonne/ Year
HaFS_to_compost = HAFS_TO_COMPOST_FRACTION*HaFS_Waste+HaFS_to_compost_change	Tonne/ Year
HaFS_to_landfill = HaFS_Waste*HAFS_TO_LANDFILL_FRACTION+HaFS_to_landfill_change	Tonne/ Year
HaFS_to_incineration = HaFS_Waste*HAFS_TO_INCINERATION_FRACTION+HaFS_to_incineration_change	Tonne/ Year
HaFS_waste_reduction = MIN(HAFS_EDIBLE_SURPLUS_FRACTION*initial_HaFS_waste, initial_HaFS_waste*RAMP(HAFS_REDUCTION_FRACTION/100))	Tonne/ Year
initial_HaFS_waste = INIT(HaFS_Food*HAFS_WASTE_FRACTION)	Tonne/ Year
urban_farming_to_HaFS = RAMP(URBAN_FARMING_TO_HAFS_CHANGE_FRACTION/100)*INIT(HaFS_food_demand)	Tonne/ Year
Urban_HaFS_Businesses[Restaurants](t) = Urban_HaFS_Businesses[Restaurants](t - dt) + (HaFS_growth[Restaurants]) * dt	Outlet
Urban_HaFS_Businesses[Pubs](t) = Urban_HaFS_Businesses[Pubs](t - dt) + (HaFS_growth[Pubs]) * dt	Outlet
Urban_HaFS_Businesses[Education](t) = Urban_HaFS_Businesses[Education](t - dt) + (HaFS_growth[Education]) * dt	Outlet
Urban_HaFS_Businesses[Healthcare](t) = Urban_HaFS_Businesses[Healthcare](t - dt) + (HaFS_growth[Healthcare]) * dt	Outlet
Urban_HaFS_Businesses[Hotels](t) = Urban_HaFS_Businesses[Hotels](t - dt) + (HaFS_growth[Hotels]) * dt	Outlet
Urban_HaFS_Businesses[Quick_Service](t) = Urban_HaFS_Businesses[Quick_Service](t - dt) + (HaFS_growth[Quick_Service]) * dt	Outlet
Urban_HaFS_Businesses[Services](t) = Urban_HaFS_Businesses[Services](t - dt) + (HaFS_growth[Services]) * dt	Outlet
Urban_HaFS_Businesses[Leisure](t) = Urban_HaFS_Businesses[Leisure](t - dt) + (HaFS_growth[Leisure]) * dt	Outlet

Urban_HaFS_Businesses[Others](t) = Urban_HaFS_Businesses[Others](t - dt) + (HaFS_growth[Others]) * dt	Outlet
INFLOWS:	
HaFS_growth[HaFs_businesses] = Urban_HaFS_Businesses*HAFS_GROWTH_INACTIVATION*CGROWTH(HAFS_GROWTH_FRACTION)	Outlet/ Year
HaFS_inflow = HaFS_purchase + urban_farming_to_HaFS	Tonne/ Year

Table A1.6. Household Food, Surplus, and Waste Equations

EQUATION	**UNIT**
Household_Food(t) = Household_Food(t - dt) + (household_from_other_sources + household_purchase - household_waste_rate - household_consumption - household_surplus) * dt	Tonne
INFLOWS:	
household_from_other_sources = total_redistribution+urban_farming_to_household	Tonne/ Year
household_purchase = household_shortfall+household_expected_outflow	Tonne/ Year
OUTFLOWS:	
household_waste_rate = Household_Food*HOUSEHOLD_WASTE_FRACTION-household_waste_reduction-household_to_animal_feed_change	Tonne/ Year
household_consumption = Urban_Population*PER_CAPITA_NUTRIENT_CONSUMPTION	Tonne/ Year
household_surplus = household_total_to_pet_feed	Tonne/ Year
household_expected_outflow = household_surplus+household_consumption+household_waste_rate	Tonne/ Year
household_demand = Urban_Population*HOUSEHOLD_PER_CAPITA_FOOD_PURCHASE	Tonne

household_shortfall = (household_demand-Household_Food)/STOCK_ADJUSTMENT_TIME-household_from_other_sources	Tonne/ Year
household_to_AD_change = RAMP(HOUSEHOLD_TO_AD_CHANGE_FRACTION/100)*initial_household_waste	Tonne/ Year
home_composting_change = RAMP(HOUSEHOLD_COMPOSTING_CHANGE_FRACTION/100)*initial_household_waste	Tonne/ Year
household_to_animal_feed_change = RAMP(HOUSEHOLD_TO_ANIMAL_FEED_CHANGE_FRACTION/100)*initial_household_waste	Tonne/ Year
household_to_incineration_change = RAMP(HOUSEHOLD_TO_INCINERATION_CHANGE_FRACTION/100)*initial_household_waste	Tonne/ Year
household_to_landfill_change = RAMP(HOUSEHOLD_TO_LANDFILL_CHANGE_FRACTION/100)*initial_household_waste	Tonne/ Year
household_total_to_pet_feed = household_to_animal_feed_change+HOUSEHOLD_INITIAL_TO_PET_FEED	Tonne/ Year
Household_Waste(t) = Household_Waste(t - dt) + (household_waste_rate - household_to_AD - household_to_incineration - home_composting - household_to_sewer - household_to_landfill) * dt	Tonne
INFLOWS:	
household_waste_rate = Household_Food*HOUSEHOLD_WASTE_FRACTION-household_waste_reduction-household_to_animal_feed_change	Tonne/ Year
OUTFLOWS:	
household_to_AD = household_to_AD_change+Household_Waste*HOUSEHOLD_TO_AD_FRACTION	Tonne/ Year
household_to_incineration = Household_Waste*HOUSEHOLD_TO_INCINERATION_FRACTION+household_to_incineration_change	Tonne/ Year

home_composting = home_composting_change+HOME_COMPOSTING_FRACTION*Household_Waste	Tonne/ Year
household_to_sewer = HOUSEHOLD_TO_SEWER_FRACTION*Household_Waste	Tonne/ Year
household_to_landfill = HOUSEHOLD_TO_LANDFILL_FRACTION*Household_Waste+household_to_landfill_change	Tonne/ Year
household_waste_reduction = MIN(HOUSEHOLD_EDIBLE_FRACTION*initial_household_waste, initial_household_waste*RAMP(HOUSEHOLD_REDUCTION_FRACTION/100))	Tonne/ Year
initial_household_waste = INIT(Household_Food*HOUSEHOLD_WASTE_FRACTION)	Tonne/ Year
total_redistribution = HaFS_total_redistribution + manufacture_total_redistribution + production_total_redistribution + retail_total_redistribution	Tonne/ Year
urban_farming_to_household = RAMP(URBAN_FARMING_TO_HH_CHANGE_FRACTION/100)*INIT(household_demand)	Tonne/ Year
Urban_Population(t) = Urban_Population(t - dt) + (population_growth_rate) * dt	Persons
INFLOWS:	
population_growth_rate = Urban_Population*POPULATION_GROWTH_INACTIVATION* CGROWTH(POPULATION_GROWTH_FRACTION)	Persons / Year
household_inflow = household_purchase + household_from_other_sources	Tonne/ Year
total_food_shopping_distance = INIT(Urban_Population)*FOOD_SHOPPING_DISTANCE_PER_PERSON	km/ Year

Table A1.7. Urban Surplus and Waste Equations

EQUATION	UNIT

total_food_surplus_and_waste = HaFS_waste_rate + household_surplus + HaFS_surplus + household_waste_rate + manufacture_surplus + manufacture_waste_rate + production_surplus + production_waste_rate + retail_surplus + retail_waste_rate	Tonne/ Year
Total_Food_Waste = total_food_surplus_and_waste- total_redistribution_and_animal_feed	Tonne/ Year
New_Food_Waste_Definition = total_food_surplus_and_waste- total_redistribution	Tonne/ Year
total_redistribution = HaFS_total_redistribution + manufacture_total_redistribution + production_total_redistribution + retail_total_redistribution	Tonne/ Year
total_redistribution_and_animal_feed = HaFS_total_redistribution + household_total_to_pet_feed + manufacture_total_redistribution + manufacture_total_to_animal_feed + production_total_redistribution + production_total_to_animal_feed + retail_total_redistribution + retail_total_to_animal_feed	Tonne/ Year
collected_food_surplus_and_waste = commercial_food_waste_to_compost + total_food_waste_to_AD + total_food_waste_to_incineration + total_food_waste_to_landfill + total_surplus_to_pig_feed	Tonne/ Year
commercial_food_waste_to_compost = HaFS_to_compost + manufacture_to_compost + retail_to_compost	Tonne/ Year
total_food_waste_to_AD = HaFS_to_AD + household_to_AD + manufacture_to_AD + production_to_AD + retail_to_AD	Tonne/ Year
total_food_waste_to_compost = commercial_food_waste_to_compost + home_composting + production_to_compost	Tonne/ Year
total_food_waste_to_incineration = HaFS_to_incineration + household_to_incineration + manufacture_to_incineration + production_to_incineration + retail_to_incineration	Tonne/ Year
total_food_waste_to_landfill = HaFS_to_landfill + household_to_landfill + manufacture_to_landfill + production_to_landfill + retail_to_landfill	Tonne/ Year
total_surplus_to_pig_feed = manufacture_total_to_animal_feed + production_total_to_animal_feed + retail_total_to_animal_feed	Tonne/ Year
commercial_food_waste_to_AD = HaFS_to_AD + manufacture_to_AD + production_to_AD + retail_to_AD	Tonne/ Year

commercial_food_waste_to_incineration = HaFS_to_incineration + manufacture_to_incineration + production_to_incineration + retail_to_incineration	Tonne/ Year
commercial_food_waste_to_landfill = HaFS_to_landfill + manufacture_to_landfill + production_to_landfill + retail_to_landfill	Tonne/ Year

Table A1.8. Energy Footprint of Food Sector Equations

EQUATION	**UNIT**
energy_footprint_of_redistribution[Fuels] = total_surplus_redistribution*ENERGY_USE_PER_TONNE_OF_REDISTRIBUTION	MWh/ Year
energy_footprint_of_surplus_and_waste_transport = energy_for_food_surplus_&_waste_collection+energy_for_digestate_transport	MWh/ Year
energy_footprint_of_water_abstraction = ENERGY_INTENSITY_OF_WATER_USE*total_water_footprint	MWh/ Year
energy_for_digestate_transport = (total_food_waste_to_AD+commercial_food_waste_to_compost)*transportation_energy_per_tonne_of_waste/WASTE_TO_AD_&_COMPOST_CONVERSION_FACTOR	MWh/ Year
energy_for_food_surplus_&_waste_collection = collected_food_surplus_and_waste*transportation_energy_per_tonne_of_waste	MWh/ Year
ENERGY_USE_PER_TONNE_OF_HAFS_FOOD[Fuels] = ENERGY_CONSUMPTION_OF_UK_HAFS/TOTAL_UK_HAFS_FOOD	MWh/ Tonne
energy_use_per_tonne_of_household_food[Electricity] = ENERGY_CONSUMPTION_OF_UK_HOUSEHOLD_FOOD[Electricity]/TOTAL_UK_HOUSEHOLD_FOOD	MWh/ Tonne
energy_use_per_tonne_of_household_food[Natural_Gas] = ENERGY_CONSUMPTION_OF_UK_HOUSEHOLD_FOOD[Natural_Gas]/TOTAL_UK_HOUSEHOLD_FOOD	MWh/ Tonne
energy_use_per_tonne_of_household_food[Oil] = shopping_energy_per_tonne_of_food	MWh/ Tonne
energy_use_per_tonne_of_household_food[Solid_Fuels] = 0	MWh/ Tonne

ENERGY_USE_PER_TONNE_OF_MANUFACTURE_FOOD[Fuels] = ENERGY_CONSUMPTION_OF_UK_FOOD_MANUFACTURE/TOTAL_UK_MANUFACTURE_FOOD	MWh/ Tonne
energy_use_per_tonne_of_primary_production[Fuels] = ENERGY_CONSUMPTION_OF_UK_AGRICULTURE/TOTAL_UK_PRIMARY_PRODUCTION	MWh/ Tonne
energy_use_per_tonne_of_retail_food[Electricity] = ENERGY_CONSUMPTION_OF_UK_RETAIL[Electricity]/TOTAL_UK_RETAIL_FOOD	MWh/ Tonne
energy_use_per_tonne_of_retail_food[Natural_Gas] = ENERGY_CONSUMPTION_OF_UK_RETAIL[Natural_Gas]/TOTAL_UK_RETAIL_FOOD	MWh/ Tonne
energy_use_per_tonne_of_retail_food[Oil] = (UK_transportation_energy_for_food_products+ENERGY_CONSUMPTION_OF_UK_RETAIL[Electricity])/TOTAL_UK_RETAIL_FOOD	MWh/ Tonne
energy_use_per_tonne_of_retail_food[Solid_Fuels] = ENERGY_CONSUMPTION_OF_UK_RETAIL[Solid_Fuels]/TOTAL_UK_RETAIL_FOOD	MWh/ Tonne
HaFS_energy_consumption[Fuels] = HaFS_inflow*ENERGY_USE_PER_TONNE_OF_HAFS_FOOD	MWh/ Year
household_energy_consumption[Electricity] = energy_use_per_tonne_of_household_food[Electricity]*household_inflow	MWh/ Year
household_energy_consumption[Natural_Gas] = energy_use_per_tonne_of_household_food[Natural_Gas]*household_inflow	MWh/ Year
household_energy_consumption[Oil] = energy_use_per_tonne_of_household_food[Oil]*household_inflow	MWh/ Year
household_energy_consumption[Solid_Fuels] = energy_use_per_tonne_of_household_food[Solid_Fuels]*household_inflow	MWh/ Year
household_food_shopping_energy_use = total_food_shopping_distance*ENERGY_CONSUMPTION_OF_AVERAGE_CAR	MWh/ Year
manufacture_energy_consumption[Fuels] = manufacture_acquisition*ENERGY_USE_PER_TONNE_OF_MANUFACTURE_FOOD	MWh/ Year

net_energy_footprint_of_AD[Electricity] = total_food_waste_to_AD*(NET_ELECTRICITY_PER_TONNE_OF_AD+NET_ENERGY_PER_TONNE_OF_REPLACED_FERTILISER[Electricity])	MWh/ Year
net_energy_footprint_of_AD[Natural_Gas] = 0	MWh/ Year
net_energy_footprint_of_AD[Oil] = total_food_waste_to_AD*NET_ENERGY_PER_TONNE_OF_REPLACED_FERTILISER[Oil]	MWh/ Year
net_energy_footprint_of_AD[Solid_Fuels] = 0	MWh/ Year
net_energy_footprint_of_composting[Fuels] = total_food_waste_to_compost*NET_ENERGY_PER_TONNE_OF_REPLACED_FERTILISER	MWh/ Year
net_energy_footprint_of_incineration = NET_ENERGY_PER_TONNE_OF_INCINERATION*total_food_waste_to_incineration	MWh/ Year
net_energy_footprint_of_landfill = total_food_waste_to_landfill*NET_ENERGY_PER_TONNE_OF_LANDFILL	MWh/ Year
net_energy_footprint_of_replaced_animal_feed = NET_ENERGY_PER_TONNE_OF_REPLACED_PIG_FEED*total_surplus_to_pig_feed+PET_FEED_AVOIDED_ENERGY*household_total_to_pet_feed	MWh/ Year
net_energy_footprint_of_sewer[Electricity] = household_to_sewer*(NET_ELECTRICITY_PER_TONNE_OF_SEWER_TREATMENT+NET_ENERGY_PER_TONNE_OF_REPLACED_FERTILISER[Electricity])	MWh/ Year
net_energy_footprint_of_sewer[Natural_Gas] = 0	MWh/ Year
net_energy_footprint_of_sewer[Oil] = household_to_sewer*NET_ENERGY_PER_TONNE_OF_REPLACED_FERTILISER[Oil]	MWh/ Year
net_energy_footprint_of_sewer[Solid_Fuels] = 0	MWh/ Year
primary_production_energy_consumption[Fuels] = energy_use_per_tonne_of_primary_production*primary_production_rate	MWh/ Year
retail_energy_consumption[Fuels] = retail_acquisition*energy_use_per_tonne_of_retail_food	MWh/ Year

shopping_energy_per_tonne_of_food = household_food_shopping_energy_use/household_inflow	MWh/ Tonne
transportation_energy_per_tonne_of_waste = AVERAGE_COLLECTION_DISTANCE*AVERAGE_TRANSPORT_ENERGY_PER_TONNE_KM	MWh/ Tonne
UK_transportation_energy_for_food_products = FOOD_PRODUCTS_ROAD_TRANSPORT*AVERAGE_TRANSPORT_ENERGY_PER_TONNE_KM	MWh/ Year
electricity_footprint_of_food = HaFS_energy_consumption[Electricity] + household_energy_consumption[Electricity] + manufacture_energy_consumption[Electricity] + primary_production_energy_consumption[Electricity] + retail_energy_consumption[Electricity]	MWh/ Year
total_energy_footprint = SUM(net_energy_footprint_of_AD[*]) + SUM(HaFS_energy_consumption[*]) + SUM(energy_footprint_of_redistribution[*]) + SUM(household_energy_consumption[*]) + SUM(manufacture_energy_consumption[*]) + SUM(net_energy_footprint_of_composting[*]) + net_energy_footprint_of_replaced_animal_feed + SUM(primary_production_energy_consumption[*]) + energy_footprint_of_water_abstraction + net_energy_footprint_of_landfill + energy_footprint_of_surplus_and_waste_transport + net_energy_footprint_of_incineration + SUM(retail_energy_consumption[*]) + SUM(net_energy_footprint_of_sewer[*])	MWh/ Year

Table A1.9. Water Footprint of Food Sector Equations

EQUATIONS	**UNIT**
HaFS_water_consumption = WATER_USE_PER_TONNE_OF_HAFS*HaFS_inflow	m^3/ Year
household_water_consumption = WATER_USE_PER_TONNE_OF_HOUSEHOLD*household_inflow	m^3/ Year

manufacture_water_consumption = WATER_USE_PER_TONNE_OF_MANUFACTURE*manufacture_acquisition	m^3/ Year
primary_production_water_consumption = water_abstraction_per_tonne_of_production*primary_production_rate	m^3/ Year
retail_water_consumption = retail_acquisition*WATER_USE_PER_TONNE_OF_RETAIL	m^3/ Year
water_abstraction_for_electricity_generation = electricity_footprint_of_food*FRESHWATER_ABSTRACTION_PER_MWh_ELECTRICITY	m^3/ Year
water_abstraction_per_tonne_of_production = BLUE_WATER_FOOTPRINT_OF_UK_PRIMARY_PRODUCTION/TOTAL_UK_PRIMARY_FOOD_CONSUMPTION	m^3/ Tonne
water_footprint_of_AD = total_food_waste_to_AD*NET_WATER_PER_TONNE_OF_AD+FRESHWATER_ABSTRACTION_PER_MWh_ELECTRICITY*net_energy_footprint_of_AD[Electricity]	m^3/ Year
water_footprint_of_animal_feed = PIG_FEED_AVOIDED_WATER*total_surplus_to_pig_feed+PET_FEED_AVOIDED_WATER*household_total_to_pet_feed	m^3/ Year
water_footprint_of_compost = NET_WATER_PER_TONNE_OF_COMPOST*total_food_waste_to_compost	m^3/ Year
water_footprint_of_incineration = total_food_waste_to_incineration*NET_WATER_PER_TONNE_OF_INCINERATION +FRESHWATER_ABSTRACTION_PER_MWh_ELECTRICITY*net_energy_footprint_of_incineration	m^3/ Year
water_footprint_of_landfilling = total_food_waste_to_landfill*NET_WATER_PER_TONNE_OF_LANDFILL+FRESHWATER_ABSTRACTION_PER_MWh_ELECTRICITY*net_energy_footprint_of_landfill	m^3/ Year
water_footprint_of_redistribution = energy_footprint_of_redistribution[Electricity]*FRESHWATER_ABSTRACTION_PER_MWh_ELECTRICITY	m^3/ Year
water_footprint_of_sewer = NET_WATER_PER_TONNE_OF_SEWER*household_to_sewer	m^3/ Year

total_water_footprint = HaFS_water_consumption + household_water_consumption + manufacture_water_consumption + primary_production_water_consumption + retail_water_consumption + water_abstraction_for_electricity_generation + water_footprint_of_AD + water_footprint_of_animal_feed + water_footprint_of_compost + water_footprint_of_incineration + water_footprint_of_landfilling + water_footprint_of_redistribution + water_footprint_of_sewer	m^3/ Year

Table A1.10. Carbon Footprint of Food Sector Equations

EQUATION	UNIT
AD_carbon_footprint = (net_emission_fracion_of_AD_electricity+NET_EMISSION_PER_TONNE_OF_REPLACED_FERTILISER)*total_food_waste_to_AD	Tonne CO_{2e}/ Year
carbon_footprint_of_animal_feed = total_surplus_to_pig_feed*PIG_FEED_AVOIDED_EMISSION+PET_FEED_AVOIDED_EMISSION*household_total_to_pet_feed	Tonne CO_{2e}/ Year
carbon_footprint_of_composting = NET_EMISSION_PER_TONNE_OF_REPLACED_FERTILISER*total_food_waste_to_compost	Tonne CO_{2e}/ Year
carbon_footprint_of_energy_for_water_abstraction = FUELS_EMISSION_FACTOR[Electricity]*energy_footprint_of_water_abstraction	Tonne CO_{2e}/ Year
carbon_footprint_of_incineration = total_food_waste_to_incineration*INCINERATION_NET_EMISSION_FRACTION	Tonne CO_{2e}/ Year
carbon_footprint_of_landfill = total_food_waste_to_landfill*LANDFILL_NET_EMISSION_FRACTION	Tonne CO_{2e}/ Year
carbon_footprint_of_redistribution = total_surplus_redistribution*EMISSION_PER_TONNE_OF_REDISTRIBUTION	Tonne CO_{2e}/ Year

carbon_footprint_of_surplus_and_waste_transport = energy_footprint_of_surplus_and_waste_transport*FUELS_EMISSION_FACTOR[Oil]	Tonne CO_{2e}/ Year
emission_per_tonne_of_HaFS = SUM(ENERGY_USE_PER_TONNE_OF_HAFS_FOOD*FUELS_EMISSION_FACTOR)	Tonne CO_{2e}/ Tonne
emission_per_tonne_of_household = SUM(energy_use_per_tonne_of_household_food*FUELS_EMISSION_FACTOR)	Tonne CO_{2e}/ Tonne
emission_per_tonne_of_manufacture = SUM(ENERGY_USE_PER_TONNE_OF_MANUFACTURE_FOOD*FUELS_EMISSION_FACTOR)	Tonne CO_{2e}/ Tonne
emission_per_tonne_of_production = UK_AGRICULTURE_TERRITORIAL_EMISSIONS/TOTAL_UK_PRIMARY_PRODUCTION	Tonne CO_{2e}/ Tonne
emission_per_tonne_of_production_electricity = FUELS_EMISSION_FACTOR[Electricity]*energy_use_per_tonne_of_primary_production[Electricity]	Tonne CO_{2e}/ Tonne
emission_per_tonne_of_retail = SUM(energy_use_per_tonne_of_retail_food*FUELS_EMISSION_FACTOR)	Tonne CO_{2e}/ Tonne
HaFS_emission = HaFS_inflow*emission_per_tonne_of_HaFS	Tonne CO_{2e}/ Year
household_emission = emission_per_tonne_of_household*household_inflow	Tonne CO_{2e}/ Year
manufacture_emission = emission_per_tonne_of_manufacture*manufacture_acquisition	Tonne CO_{2e}/ Year
net_emission_fracion_of_AD_electricity = NET_ELECTRICITY_PER_TONNE_OF_AD*FUELS_EMISSION_FACTOR[Electricity]	Tonne CO_{2e}/ Tonne
primary_production_emission = (emission_per_tonne_of_production_electricity+emission_per_tonne_of_production)*primary_production_rate	Tonne CO_{2e}/ Year

retail_emission = retail_acquisition*emission_per_tonne_of_retail	Tonne CO_{2e}/ Year
Sewer_electricity_emission_factor = NET_ELECTRICITY_PER_TONNE_OF_SEWER_TREATMENT*FUELS_EMISSION_FACTOR[Electricity]	Tonne CO_{2e}/ Tonne
Sewer_treatment_carbon_footprint = (Sewer_electricity_emission_factor+NET_EMISSION_PER_TONNE_OF_REPLACED_FERTILISER)*household_to_sewer	Tonne CO_{2e}/ Year
total_carbon_footprint = Sewer_treatment_carbon_footprint + carbon_footprint_of_energy_for_water_abstraction + HaFS_emission + AD_carbon_footprint + carbon_footprint_of_animal_feed + carbon_footprint_of_composting + carbon_footprint_of_incineration + carbon_footprint_of_landfill + carbon_footprint_of_redistribution + carbon_footprint_of_surplus_and_waste_transport + household_emission + manufacture_emission + primary_production_emission + retail_emission	Tonne CO_{2e}/ Year

Table A1.11. Socio-Economic Impacts Equations

EQUATION	**UNIT**
Very_Low_Food_Secure_Population(t) = Very_Low_Food_Secure_Population(t - dt) + (very_low_food_security_rate - suffering_very_low_food_security) * dt	Person
INFLOWS:	
very_low_food_security_rate = population_with_very_low_food_security-redistribution_beneficiaries	Person/ Year
OUTFLOWS:	
suffering_very_low_food_security = Very_Low_Food_Secure_Population/MEASUREMENT_PERIOD	Person/ Year
population_with_very_low_food_security = VERY_LOW_FOOD_SECURITY_FRACTION*Urban_Population	Person/ Year
VERY_LOW_FOOD_SECURITY_FRACTION = TIME	Per Year

Low_Food_Secure_Population(t) = Low_Food_Secure_Population(t - dt) + (low_food_security_rate - suffering_low_food_security) * dt	Person
INFLOWS:	
low_food_security_rate = population_with_low_food_security+redistribution_beneficiaries	Person/ Year
OUTFLOWS:	
suffering_low_food_security = Low_Food_Secure_Population/MEASUREMENT_PERIOD	Person/ Year
population_with_low_food_security = LOW_FOOD_SECURITY_FRACTION*Urban_Population	Person/ Year
LOW_FOOD_SECURITY_FRACTION = TIME	Per Year
food_insecure_population = suffering_very_low_food_security + suffering_low_food_security	Person/ Year
redistribution_beneficiaries = (total_redistribution-INIT(total_redistribution))/HOUSEHOLD_PER_CAPITA_FOOD_PURCHASE	Person/ Year
redistribution_benefit = total_redistribution*household_purchasing_cost_per_tonne_of_food	£/Year
redistribution_cost = REDISTRIBUTION_COST_PER_TONNE_OF_FOOD*total_redistribution	£/Year
redistribution_GVA = total_redistribution*REDISTRIBUTION_GVA_PER_TONNE_OF_SURPLUS	£/Year
household_AD_cost = SEPARATE_COLLECTION_AND_DISPOSAL_COST*household_to_AD	£/Year
household_composting_cost = home_composting*HOME_COMPOSTING_NET_COST	£/Year
household_energy_cost = SUM(HOUSEHOLD_ENERGY_COST_PER_MWH*household_energy_consumption)	£/Year
household_energy_consumption[Electricity] = energy_use_per_tonne_of_household_food[Electricity]*household_inflow	MWh/Year
household_energy_consumption[Natural_Gas] = energy_use_per_tonne_of_household_food[Natural_Gas]*household_inflow	MWh/Year
household_energy_consumption[Oil] = energy_use_per_tonne_of_household_food[Oil]*household_inflow	MWh/Year

household_energy_consumption[Solid_Fuels] = energy_use_per_tonne_of_household_food[Solid_Fuels]*household_inflow	MWh/Year
energy_use_per_tonne_of_household_food[Electricity] = ENERGY_CONSUMPTION_OF_UK_HOUSEHOLD_FOOD[Electricity]/TOTAL_UK_HOUSEHOLD_FOOD	MWh/tonne
energy_use_per_tonne_of_household_food[Natural_Gas] = ENERGY_CONSUMPTION_OF_UK_HOUSEHOLD_FOOD[Natural_Gas]/TOTAL_UK_HOUSEHOLD_FOOD	MWh/tonne
energy_use_per_tonne_of_household_food[Oil] = shopping_energy_per_tonne_of_food	MWh/tonne
energy_use_per_tonne_of_household_food[Solid_Fuels] = 0	MWh/tonne
shopping_energy_per_tonne_of_food = household_food_shopping_energy_use/household_inflow	MWh/tonne
household_food_shopping_energy_use = total_food_shopping_distance*ENERGY_CONSUMPTION_OF_AVERAGE_CAR	MWh/Year
household_water_cost = CHARGE_PER_CUBIC_METER*household_water_consumption	£/Year
household_water_consumption = WATER_USE_PER_TONNE_OF_HOUSEHOLD*household_inflow	m3/Year
household_purchasing_cost_per_tonne_of_food = HOUSEHOLD_PER_CAPITA_FOOD_COST/HOUSEHOLD_PER_CAPITA_FOOD_PURCHASE	£/Tonne
household_food_purchase_cost = household_purchasing_cost_per_tonne_of_food*household_purchase	£/Year
replaced_pet_food_benefit = household_total_to_pet_feed*PET_FEED_NET_COST	£/Year
household_incineration_and_landfill_cost = RESIDUAL_COLLECTION_AND_DISPOSAL_COST*(household_to_incineration+household_to_landfill)	£/Year
household_food_waste_treatment_cost = replaced_pet_food_benefit+household_AD_cost+household_composting_cost+household_incineration_and_landfill_cost	£/Year
household_reduction_benefit = household_waste_reduction*household_purchasing_cost_per_tonne_of_food	£/Year

household_reduction_cost = household_reduction_benefit*household_cost_benefit_ratio	£/Year
household_reduction_cost_for_government = REDUCTION_COST_FOR_GOVERNMENT_FRACTION*household_reduction_cost	£/Year
household_reduction_cost_for_manufacture = REDUCTION_COST_FOR_MANUFACTURE_FRACTION*household_reduction_cost	£/Year
household_reduction_cost_for_retail = REDUCTION_COST_FOR_RETAIL_FRACTION*household_reduction_cost	£/Year
household_reduction_net_cost = household_reduction_cost-household_reduction_benefit	£/Year
household_cost_benefit_ratio = INITIAL_HOUSEHOLD_COST_BENEFIT_RATIO/(1-RAMP(HOUSEHOLD_REDUCTION_FRACTION/100)/HOUSEHOLD_EDIBLE_FRACTION)	dmnl
incineration_gate_fees_charged_to_LA = household_to_incineration*ENERGY_FROM_WASTE_GATE_FEES	£/Year
incineration_output_from_household = household_to_incineration*ENERGY_FROM_WASTE_GATE_FEES	£/Year
Landfill_output_from_business = commercial_food_waste_to_landfill*(COMMERCIAL_WASTE_TO_LANDFILL_TRANSFER_COST-LANDFILL_TAX)	£/Year
total_landfill_output_at_basic_price = Landfill_output_from_household+Landfill_output_from_business+electricity_output_of_landfill	£/Year
landfill_operating_cost = OPERATING_COST_OF_LANDFILL*total_food_waste_to_landfill	£/Year
landfill_GVA = total_landfill_output_at_basic_price-landfill_operating_cost	£/Year
hafs_cost_per_tonne_of_food = UK_HAFS_INTERIM_CONSUMPTION/TOTAL_UK_HAFS_FOOD	£/Tonne
HaFS_food_waste_treatment_cost = HaFS_to_AD_cost+HaFS_composting_cost+HaFS_to_incineration_cost+HaFS_to_landfill_cost	£/Year
hafs_turnover_per_tonne_of_output = UK_HAFS_TURNOVER/UK_HAFS_CONSUMPTION	£/Tonne

urban_HaFS_turnover = HaFS_consumption*hafs_turnover_per_tonne_of_output	£/Year
hafs_reduction_benefit = hafs_turnover_per_tonne_of_output*HaFS_waste_reduction	£/Year
hafs_reduction_cost = hafs_reduction_benefit*hafs_cost_benefit_ratio	£/Year
hafs_reduction_net_cost = hafs_reduction_cost-hafs_reduction_benefit	£/Year
HaFS_interim_cost = hafs_cost_per_tonne_of_food*HaFS_consumption+hafs_reduction_net_cost+ HaFS_food_waste_treatment_cost	£/Year
HaFS_GVA = urban_HaFS_turnover-HaFS_interim_cost	£/Year
hafs_cost_benefit_ratio = INITIAL_HAFS_COST_BENEFIT_RATIO/(1-MIN(RAMP(HAFS_REDUCTION_FRACTION/100), HAFS_EDIBLE_FRACTION*.99)/HAFS_EDIBLE_FRACTION)	dmnl
HaFS_composting_cost = (COMMERCIAL_WASTE_COLLECTION_COST+COMMERCIAL_FOOD_WASTE_TRANSFER_COST)*(HaFS_to_compost-INIT(HaFS_to_compost))	£/year
HaFS_to_AD_cost = (COMMERCIAL_WASTE_COLLECTION_COST+COMMERCIAL_FOOD_WASTE_TRANSFER_COST)*(HaFS_to_AD-INIT(HaFS_to_AD))	£/year
HaFS_to_incineration_cost = (COMMERCIAL_WASTE_COLLECTION_COST+COMMERCIAL_WASTE_TO_INCINERATION_TRANSFER_COST)*(HaFS_to_incineration-INIT(HaFS_to_incineration))	£/year
HaFS_to_landfill_cost = (COMMERCIAL_WASTE_COLLECTION_COST+COMMERCIAL_WASTE_TO_LANDFILL_TRANSFER_COST)*(HaFS_to_landfill-INIT(HaFS_to_landfill))	£/year
retail_cost_per_tonne_of_food = TOTAL_UK_FOOD_RETAIL_INTERIM_CONSUMPTION/TOTAL_UK_RETAIL_FOOD	£/tonne
retail_food_waste_treatment_cost = retail_to_AD_cost+retail_composting_cost+retail_to_incineration_cost+retail_to_landfill_cost	£/year
retail_turnover_per_tonne_of_food = UK_RETAIL_TURNOVER/TOTAL_UK_RETAIL_FOOD	£/tonne
urban_retail_turnover = retail_to_consumer*retail_turnover_per_tonne_of_food	£/year

retail_reduction_benefit = retail_turnover_per_tonne_of_food*retail_waste_reduction	£/year
retail_reduction_cost = retail_reduction_benefit*retail_cost_benefit_ratio	£/year
retail_reduction_net_cost = retail_reduction_cost-retail_reduction_benefit	£/year
retail_interim_cost = retail_cost_per_tonne_of_food*retail_to_consumer+retail_reduction_net_cost+ retail_food_waste_treatment_cost+household_reduction_cost_for_retail	£/year
retail_GVA = urban_retail_turnover-retail_interim_cost	£/year
retail_cost_benefit_ratio = INITIAL_RETAIL_COST_BENEFIT_RATIO/(1-MIN(RAMP(RETAIL_REDUCTION_FRACTION/100), RETAIL_EDIBLE_FRACTION*.99)/RETAIL_EDIBLE_FRACTION)	dmnl
retail_composting_cost = (COMMERCIAL_WASTE_COLLECTION_COST+COMMERCIAL_FOOD_WASTE_TRANSFER_COST)*(retail_to_compost-INIT(retail_to_compost))	£/year
retail_to_AD_cost = (COMMERCIAL_WASTE_COLLECTION_COST+COMMERCIAL_FOOD_WASTE_TRANSFER_COST)*(retail_to_AD-INIT(retail_to_AD))	£/year
retail_to_incineration_cost = (COMMERCIAL_WASTE_COLLECTION_COST+COMMERCIAL_WASTE_TO_INCINERATION_TRANSFER_COST)*(retail_to_incineration-INIT(retail_to_incineration))	£/year
retail_to_landfill_cost = (COMMERCIAL_WASTE_COLLECTION_COST+COMMERCIAL_WASTE_TO_LANDFILL_TRANSFER_COST)*(retail_to_landfill-INIT(retail_to_landfill))	£/year
wholesale_GVA = retail_GVA*WHOLESALE_TO_RETAIL_GVA_RATIO	£/year
manufacture_cost_per_tonne_of_food = TOTAL_UK_MANUFACTURE_INTERIM_CONSUMPTION/TOTAL_UK_MANUFACTURE_FOOD	£/Tonne
manufacture_turnover_per_tonne_of_food = UK_MANUFACTURE_TURNOVER/TOTAL_UK_MANUFACTURE_FOOD	£/Tonne
manufacture_food_waste_treatment_cost = manufacture_to_AD_cost+manufacture_composting_cost+manufacture_to_incineration_cost+manufacture_to_landfill_cost	£/year
urban_manufacture_turnover = manufacture_to_retail*manufacture_turnover_per_tonne_of_food	£/year

manufacture_reduction_benefit = manufacture_turnover_per_tonne_of_food*manufacture_waste_reduction	£/year
manufacture_reduction_cost = manufacture_cost_benefit_ratio*manufacture_reduction_benefit	£/year
manufacture_reduction_net_cost = manufacture_reduction_cost-manufacture_reduction_benefit	£/year
manufacture_interim_cost = manufacture_cost_per_tonne_of_food*manufacture_to_retail+manufacture_reduction_net_cost+manufacture_food_waste_treatment_cost+household_reduction_cost_for_manufacture	£/year
manufacture_GVA = urban_manufacture_turnover-manufacture_interim_cost	£/year
manufacture_composting_cost = (COMMERCIAL_WASTE_COLLECTION_COST+COMMERCIAL_FOOD_WASTE_TRANSFER_COST)*(manufacture_to_compost-INIT(manufacture_to_compost))	£/year
c manufacture_to_AD_cost = (COMMERCIAL_WASTE_COLLECTION_COST+COMMERCIAL_FOOD_WASTE_TRANSFER_COST)*(manufacture_to_AD-INIT(manufacture_to_AD))	£/year
manufacture_to_incineration_cost = (COMMERCIAL_WASTE_COLLECTION_COST+COMMERCIAL_WASTE_TO_INCINERATION_TRANSFER_COST)*(manufacture_to_incineration-INIT(manufacture_to_incineration))	£/year
manufacture_to_landfill_cost = (COMMERCIAL_WASTE_COLLECTION_COST+COMMERCIAL_WASTE_TO_LANDFILL_TRANSFER_COST)*(manufacture_to_landfill-INIT(manufacture_to_landfill))	£/year
manufacture_cost_benefit_ratio = INITIAL_MANUFACTURE_COST_BENEFIT_RATIO/(1-MIN(RAMP(MANUFACTURE_REDUCTION_FRACTION/100), MANUFACTURE_EDIBLE_FRACTION*.99)/MANUFACTURE_EDIBLE_FRACTION)	dmnl
primary_production_turnover = agriculture_turnover_per_tonne_of_food*production_to_manufacture	£/year
production_food_waste_treatment_cost = production_to_AD_cost+production_composting_cost+production_to_incineration_cost+production_to_landfill_cost	£/year

production_reduction_benefit = agriculture_turnover_per_tonne_of_food*production_waste_reduction	£/year
production_reduction_cost = production_cost_benefit_ratio*production_reduction_benefit	£/year
production_reduction_net_cost = production_reduction_cost-production_reduction_benefit	£/year
production_interim_cost = agriculture_cost_per_tonne_of_food*production_to_manufacture+production_reduction_net_cost+production_food_waste_treatment_cost	£/year
production_GVA = primary_production_turnover-production_interim_cost	£/year
production_cost_benefit_ratio = INITIAL_PRODUCTION_COST_BENEFIT_RATIO/(1-MIN(RAMP(PRODUCTION_REDUCTION_FRACTION/100), PRODUCTION_EDIBLE_FRACTION*.99)/PRODUCTION_EDIBLE_FRACTION)	dmnl
agriculture_cost_per_tonne_of_food = TOTAL_UK_AGRICULTURE_INTERIM_CONSUMPTION/TOTAL_UK_PRIMARY_PRODUCTION	£/tonne
agriculture_turnover_per_tonne_of_food = TOTAL_UK_AGRICULTURE_OUTPUT /TOTAL_UK_PRIMARY_PRODUCTION	£/tonne
production_composting_cost = (production_to_compost-INIT(production_to_compost))*(OPERATING_COST_OF_COMPOSTING+CAPITAL_COST_OF_COMPOSTING-COMPOST_PRICE_PER_TONNE_OF_FOOD_WASTE)	£/year
production_to_AD_cost = (COMMERCIAL_FOOD_WASTE_TRANSFER_COST+COMMERCIAL_WASTE_COLLECTION_COST)*(production_to_AD-INIT(production_to_AD))	£/year
production_to_incineration_cost = (COMMERCIAL_WASTE_COLLECTION_COST+COMMERCIAL_WASTE_TO_INCINERATION_TRANSFER_COST)*(production_to_incineration-INIT(production_to_incineration))	£/year
production_to_landfill_cost = (COMMERCIAL_WASTE_COLLECTION_COST+COMMERCIAL_WASTE_TO_LANDFILL_TRANSFER_COST)*(production_to_landfill-INIT(production_to_landfill))	£/year

replaced_animal_feed_benefit = total_surplus_to_pig_feed*PIG_FEED_REPLACEMENT_BENEFIT	£/year
animal_feed_operating_cost = OPERATING_COST_OF_PIG_FEED*total_surplus_to_pig_feed	£/year
animal_feed_GVA = replaced_animal_feed_benefit-animal_feed_operating_cost	£/year
incineration_output_from_business = commercial_food_waste_to_incineration*COMMERCIAL_WASTE_TO_INCINERATION_TRANSFER_COST	£/year
total_incineration_output_at_basic_price = incineration_output_from_household+incineration_output_from_business+electricity_output_of_incineration	£/year
incineration_operating_cost = OPERATING_COST_OF_INCINERATION*total_food_waste_to_incineration	£/year
incineration_GVA = total_incineration_output_at_basic_price-incineration_operating_cost	£/year
Landfill_output_from_household = household_to_landfill*(LANDFILL_GATE_FEES-LANDFILL_TAX)	£/year
AD_gate_fees_charged_to_LA = household_to_AD*AD_GATE_FEES	£/year
landfill_gate_fees_charged_to_LA = household_to_landfill*LANDFILL_GATE_FEES	£/year
AD_output_from_household = household_to_AD*AD_GATE_FEES	£/year
AD_output_from_business = commercial_food_waste_to_AD*COMMERCIAL_FOOD_WASTE_TRANSFER_COST	£/year
sales_revenue_of_AD = FEED_IN_TARIFF_GENERATION_AND_EXPORT_PRICE*-net_energy_footprint_of_AD[Electricity]	£/year
net_energy_footprint_of_AD[Electricity] = total_food_waste_to_AD*(NET_ELECTRICITY_PER_TONNE_OF_AD+NET_ENERGY_PER_TONNE_OF_REPLACED_FERTILISER[Electricity])	MWh/year
total_AD_output_at_basic_price = AD_output_from_household+AD_output_from_business+sales_revenue_of_AD	£/year
AD_operating_cost = OPERATING_COST_OF_AD*total_food_waste_to_AD	£/year

AD_GVA = total_AD_output_at_basic_price-AD_operating_cost	£/year
sales_revenue_of_composting = COMPOST_PRICE_PER_TONNE_OF_FOOD_WASTE*collected_food_waste_for_in_vessel_composting	£/year
in_vessel_composting_output = COMMERCIAL_FOOD_WASTE_TRANSFER_COST*collected_food_waste_for_in_vessel_composting	£/year
total_composting_output_at_basic_price = sales_revenue_of_composting+in_vessel_composting_output	£/year
composting_operating_cost = OPERATING_COST_OF_COMPOSTING*collected_food_waste_for_in_vessel_composting	£/year
composting_GVA = total_composting_output_at_basic_price-composting_operating_cost	£/year
electricity_output_of_incineration = WHOLESALE_ELECTRICITY_PRICE*-net_energy_footprint_of_incineration	£/year
net_energy_footprint_of_incineration = NET_ENERGY_PER_TONNE_OF_INCINERATION*total_food_waste_to_incineration	MWh/year
electricity_output_of_landfill = WHOLESALE_ELECTRICITY_PRICE*-net_energy_footprint_of_landfill	£/year
net_energy_footprint_of_landfill = total_food_waste_to_landfill*NET_ENERGY_PER_TONNE_OF_LANDFILL	MWh/year
total_AD_cost = (OPERATING_COST_OF_AD+CAPITAL_COST_OF_AD)*total_food_waste_to_AD	£/year
total_animal_feed_cost = (OPERATING_COST_OF_PIG_FEED+CAPITAL_COST_OF_PIG_FEED)*total_surplus_to_pig_feed	£/year
total_composting_cost = (OPERATING_COST_OF_COMPOSTING+CAPITAL_COST_OF_COMPOSTING)*collected_food_waste_for_in_vessel_composting	£/year
total_incineration_cost = (OPERATING_COST_OF_INCINERATION+CAPITAL_COST_OF_INCINERATION)*total_food_waste_to_incineration	£/year

total_landfill_cost = (OPERATING_COST_OF_LANDFILL+CAPITAL_COST_OF_LANDFILL)*total_food_waste_to_landfill	£/year
GOVERNMENT_COST = AD_gate_fees_charged_to_LA + household_reduction_cost + incineration_gate_fees_charged_to_LA + landfill_gate_fees_charged_to_LA + redistribution_cost	£/year
total_GVA = AD_GVA + animal_feed_GVA + composting_GVA + incineration_GVA + landfill_GVA + redistribution_GVA + replaced_animal_feed_benefit + HaFS_GVA + manufacture_GVA + production_GVA + retail_GVA + wholesale_GVA	£/year
total_household_cost = household_energy_cost + household_food_purchase_cost + household_food_waste_treatment_cost + household_water_cost	£/year
	£/year

Table A1.12. Food (Waste) Parameters, Values and Data Sources

PARAMETER	VALUE	UNIT	DOCUMENT
PRODUCTION_INITIAL_REDISTRIBUTION	51	Tonne/Year	7000 tonnes of surplus at primary production sector are redistributed (WRAP, 2020). This is equal 0.14% of 50,500,000 tonne primary production in the UK (Bajzelj et al., 2019). By multiplying it by the 371,200 tonne modelled primary production food for Bristol, it can be estimated that each year around 51 tonne is redistributed.
PRODUCTION_INITIAL_TO_ANIMAL_FEED	16299	Tonne/Year	Primary production surplus accounts for 4% of harvested food, majority of which is fed to animals (Bajzelj et al., 2019). Hence, we subtracted the primary production redistribution fraction from the 4% surplus fraction and multiplied

			the rest (which is assumed to be used as animal feed) with the modelled 371,200 tonne primary production for Bristol.
PRODUCTION_TO_AD_FRACTION	0.15	Per Year	Assumption
PRODUCTION_TO_COMPOST_FRACTION	0.7	Per Year	Assumption
PRODUCTION_TO_INCINERATION_FRACTION	0.15	Per Year	Assumption
PRODUCTION_TO_LANDFILL_FRACTION	0	Per Year	Assumption
PRODUCTION_WASTE_FRACTION	0.032	Per Year	(Bajzelj et al., 2019)
MANUFACTURE_EDIBLE_SURPLUS_FRACTION	0.53	Dimensionless	800,000 of 1,500,000 tonne (53.3%) wasted food in the UK manufacture sector is estimated to be edible (WRAP, 2020).
MANUFACTURE_INITIAL_REDISTRIBUTION	137	Tonne/Year	23,000 tonne of the UK manufacture surplus is redistributed (WRAP, 2020). Dividing this by 1,500,000 tonne of food waste in the sector, the ratio of redistribution to wasted food is around 1.53%. Multiplying this by 8,900 tonne of simulated manufacture food waste, the initial amount of redistributed manufacture surplus is estimated to be around 137 tonne per year.
MANUFACTURE_INITIAL_TO_ANIMAL_FEED	3776	Tonne/Year	635,000 tonne of manufacture surplus is fed to animals (WRAP, 2020). Dividing this by 1,500,000 tonne of food waste in the sector, the ratio of animal feed to wasted food is around 42.3%. Multiplying this by 8,900 tonne of simulated manufacture food waste, the

			initial amount of manufacture surplus which is used as animal feed is estimated to be 3,776 tonne per year.
MANUFACTURE_TO_AD_FRACTION	0.293	Per Year	440,000 of 1,500,000 tonne manufacture food waste is sent to AD or composted (WRAP, 2020). Assuming that all goes to AD, the AD fraction of manufacture food waste is 29.33%.
MANUFACTURE_TO_COMPOST_FRACTION	0	Per Year	Assumption
MANUFACTURE_TO_INCINERATION_FRACTION	0.706	Per Year	1,100,000 of 1,500,000 tonne (73.3%) manufacture food waste is incinerated (WRAP, 2020). However, as the sum of individual treatment options in the source document exceeds 1,500,000 tonne, we assume the incineration fraction is 70.6%.
MANUFACTURE_TO_LANDFILL_FRACTION	0.001	Per Year	2000 of 1,500,000 tonne (0.13%) manufacture food waste is landfilled (WRAP, 2020).
MANUFACTURE_WASTE_FRACTION	0.026	Per Year	Less than 3% of the food in the manufacture sector is wasted (Parfitt et al., 2016). The 2.6% value is estimated by dividing 1,500,000 tonne manufacture food waste (WRAP, 2020) by 58,000,000 tonne UK manufactured food (Parfitt et al., 2016).
RETAIL_EDIBLE_SURPLUS_FRACTION	1	Dimensionless	From 300,000 tonne of wasted food in UK retail sector, all is edible (WRAP, 2020).

RETAIL_INITIAL_REDISTRIBUTION	135	Tonne/ Year	17,500 tonne of retail surplus is redistributed (WRAP, 2020). Dividing this by 300,000 tonne of food waste in the sector, the ratio of redistribution to wasted food is 5.83%. Multiplying this by 2,300 tonne of simulated retail food waste in Bristol, the initial amount of redistributed retail surplus is estimated to be 135 tonnes per year.
RETAIL_INITIAL_TO_ANIMAL_FEED	208	Tonne/ Year	27000 tonne of retail surplus is fed to livestock (WRAP, 2020). Dividing this by 300,000 tonne of food waste in the sector, the ratio of animal feed to wasted food is 9%. Multiplying this by 2,300 tonne of simulated retail food waste in Bristol, the initial amount of retail surplus which is fed to animals is estimated to be 208 tonnes per year.
RETAIL_TO_AD_FRACTION	0.5	Per Year	150,000 of 300,000 tonne food waste in retail sector is sent to AD or composted (WRAP, 2020). Assuming that all goes to AD, the AD fraction of retail food waste is 50%.
RETAIL_TO_COMPOST_FRACTION	0	Per Year	Assumption
RETAIL_TO_INCINERATION_FRACTION	0.5	Per Year	150,000 of 300,000 tonne food waste in retail sector is sent to AD or composted while the other 150,000 tonne (50%) is incinerated (WRAP, 2020).
RETAIL_TO_LANDFILL_FRACTION	0	Per Year	Based on WRAP (2020), the amount of landfilled retail food waste is unknown and while it has not added up to the total of retail food waste, we assume its value is 0.

RETAIL_WASTE_FRACTION	0.007	Per Year	(Parfitt et al., 2016)
AVERAGE_PURCHASE_PER_BUSINESS[Restaurants]	30.4	Tonne/ Outlet/ Year	This is estimated by dividing the average food waste per outlet (WRAP, 2013) by 16% food waste fraction of the sector.
AVERAGE_PURCHASE_PER_BUSINESS[Pubs]	24		
AVERAGE_PURCHASE_PER_BUSINESS[Education]	22.1		
AVERAGE_PURCHASE_PER_BUSINESS[Healthcare]	39.3		
AVERAGE_PURCHASE_PER_BUSINESS[Hotels]	10.8		
AVERAGE_PURCHASE_PER_BUSINESS[Quick_Service]	15.1		
AVERAGE_PURCHASE_PER_BUSINESS[Services]	209.5		
AVERAGE_PURCHASE_PER_BUSINESS[Leisure]	40.5		
AVERAGE_PURCHASE_PER_BUSINESS[Others]	24.4		
AVERAGE_CONSUMPTION_PER_BUSINESS[Restaurants]	25.5	Tonne/ Outlet/ Year	This is estimated by reducing the 16% HaFS food waste from the ‘average purchase per business’ parameter values.
AVERAGE_CONSUMPTION_PER_BUSINESS[Pubs]	20.2		

AVERAGE_CONSUMPTION_PER_BUSINESS[Education]	18.6		
AVERAGE_CONSUMPTION_PER_BUSINESS[Healthcare]	33		
AVERAGE_CONSUMPTION_PER_BUSINESS[Hotels]	9.1		
AVERAGE_CONSUMPTION_PER_BUSINESS[Quick_Service]	12.7		
AVERAGE_CONSUMPTION_PER_BUSINESS[Services]	176		
AVERAGE_CONSUMPTION_PER_BUSINESS[Leisure]	34		
AVERAGE_CONSUMPTION_PER_BUSINESS[Others]	20.5		
HAFS_EDIBLE_SURPLUS_FRACTION	0.73	Dimensionless	800,000 of 1,100,000 tonne (72.7%) of wasted food in the UK HaFS sector is edible (WRAP, 2020).
HAFS_GROWTH_FRACTION	1.5	Per Year	Estimated based on (Parry et al., 2020)
HAFS_INITIAL_REDISTRIBUTION	10.8	Tonne/Year	1,000 tonne of the UK food surplus is redistributed (WRAP, 2020). The proportion of HaFS redistributed food to 1,100,000 tonne of wasted food is around 0.1%. Assuming the same proportion applies to the Bristol HaFS sector, around 10.8 tonnes of HaFS food surplus is redistributed.

HAFS_TO_AD_FRACTION	0.04	Per Year	40,000 of 1,100,000 tonne (roughly 4%) of HaFS food waste is sent to AD or composted (WRAP, 2020). We assume all of this goes to AD plant and non is composted.
HAFS_TO_COMPOST_FRACTION	0	Per Year	Assumption
HAFS_TO_INCINERATION_FRACTION	0.76	Per Year	840,000 of 1,100,000 tonne (around 76%) of HaFS food waste is incinerated (WRAP, 2020).
HAFS_TO_LANDFILL_FRACTION	0.2	Per Year	220,000 of 1,100,000 tonne (20%) of HaFS food waste is landfilled (WRAP, 2020).
HAFS_WASTE_FRACTION	0.16	Per Year	Estimated based on (WRAP, 2020, 2013)
HAFS_EDIBLE_FRACTION	0.73	Per Year	Estimated based on (WRAP, 2020, 2013)
HOME_COMPOSTING_FRACTION	0.07	Per Year	520,000 of 7,100,000 tonne (or 7.3%) of household food waste in 2015 was composted at homes (Gillick and Quested, 2018).
HOUSEHOLD_EDIBLE_FRACTION	0.68	Dimensionless	4,500,000 of 6,600,000 tonne food waste by the UK household is edible (WRAP, 2020).
HOUSEHOLD_INITIAL_TO_PET_FEED	2100	Tonne/Year	300,000 tonne of household food surplus is fed to pets (WRAP, 2020). Hence, the ratio of feeding food leftover to the pets to the 6,600,000 tonnes household food waste is 4.5%. Multiplying it by 100 kg per person annual food waste of households (Parry et al., 2020) means that on average 4.5 kg of food surplus per person is fed to pets. This for Bristol population is estimated to be 2100 tonne per year.

HOUSEHOLD_PER_CAPITA_FOOD_PURCHASE	0.543	Tonne/ Person	It is estimated by summing up the weight of different types of food from household food purchase survey (DEFRA, 2020).
PER_CAPITA_NUTRIENT_CONSUMPTION	0.443	Tonne/ Person/ Year	It is estimated by subtracting the 0.1 tonne per capita household food waste from the 0.543 tonne per capita food purchase.
HOUSEHOLD_TO_AD_FRACTION	0.3	Per Year	Based on Open Data Bristol (2020) and DEFRA (2021), Around 14,000 tonne of Bristol food waste is sent for AD treatment (DEFRA, 2021a; Open Data Bristol, 2020). This accounts for 30% of the simulated household food waste rate in this study.
HOUSEHOLD_TO_INCINERATION_FRACTION	0.25	Per Year	In total, 60% of household food waste is collected for AD treatment, sent to sewer, or composted at home. This implies that the remaining 40% is collected as general waste. Based on the municipal data, 56,676 tonnes (or 62%) of Bristol general waste is incinerated while the remaining 34,088 tonnes (or 38%) is landfilled (DEFRA, 2021a). This means that of the total household food waste, around 25% (40%*62%) is incinerated and 15% (40%*38%) is sent to landfill.
HOUSEHOLD_TO_LANDFILL_FRACTION	0.15	Per Year	see the description in HOUSEHOLD_TO_INCINERATION_FRACTION
HOUSEHOLD_TO_SEWER_FRACTION	0.23	Per Year	1,500,000 of 6,600,000 tonne of household food waste (i.e., 22.7%) goes down to the sewer (WRAP, 2020).

HOUSEHOLD_WASTE_FRACTION	0.184	Per Year	It's estimated by dividing 100 kg per capita average household food waste (Parry et al., 2020) by 0.543 tonne per person food purchase (DEFRA, 2020).
POPULATION_GROWTH_FRACTION	0.62	Per Year	The population of the city was 463,405 in 2018 and is projected to reach 532,716 persons in 2030 (ONS, 2020). This shows an annual growth rate of around 0.62%.
STOCK_ADJUSTMENT_TIME	1	Year	Assumption
ENERGY_CONSUMPTION_OF_AVERAGE_CAR	0.00069131	MWh/km	(BEIS, 2020a)
ENERGY_CONSUMPTION_OF_UK_HOUSEHOLD_FOOD[Electricity]	26822000	MWh/Year	This is the sum of household energy consumption for cooking, refrigeration, and dishwashing in (BEIS, 2020d). We use this data source for household electricity consumption as it provides more detailed and comprehensive data for domestic cooking, refrigeration, and dishwashing items. The data for household gas consumption is extracted from (BEIS, 2020c).
ENERGY_CONSUMPTION_OF_UK_HOUSEHOLD_FOOD[Natural_Gas]	7385050		
ENERGY_CONSUMPTION_OF_UK_HOUSEHOLD_FOOD[Oil]	0		
ENERGY_CONSUMPTION_OF_UK_HOUSEHOLD_FOOD[Solid_Fuels]	0		

NET_ELECTRICITY_PER_TONNE_OF_AD	-0.362	MWh/ Tonne	It's estimated that the Avonmouth AD plant generates 0.608 MWh electricity per tonne of food waste (Geneco, 2020). With an estimated Energy Return on Investment (EROI) of 2.48, the electricity consumption fraction is around 0.246 MWh/tonne. Hence, net electricity fraction of AD is estimated to be -0.362 MWh/tonne. It is important to acknowledge that most of generated biogas at Geneco is not converted to electricity (directly fed to gas grid). This means even a higher efficiency per tonne of food waste. To compare with other electricity generating treatment options (i.e., incineration and landfill), however, we assume all of the biogas is used for electricity generation.
net_energy_footprint_of_AD[Natural_Gas]	0	MWh/ Year	Assumption
NET_ENERGY_PER_TONNE_OF_INCINERATION	-0.519	MWh/ Tonne	Jeswani and Azapagic (2016) and Tolvik (2020) provide slightly different estimates: 519 kWh and 531 kWh per tonne of waste, respectively. We use the first for consistency with landfill data. The latter source is used for incineration and landfill emission data.
NET_ENERGY_PER_TONNE_OF_LANDFILL	-0.056	MWh/ Tonne	(Jeswani and Azapagic, 2016)
NET_ENERGY_PER_TONNE_OF_REPLACED_FERTILISER[Electricity]	-0.006	MWh/ Tonne	(Salemdeeb et al., 2017; Slorach et al., 2019)
NET_ENERGY_PER_TONNE_OF_REPLACED_FERTILISER[Natural_Gas]	0		

NET_ENERGY_PER_TONNE_OF_REPLACED_FERTILISER[Oil]	-0.041		
NET_ENERGY_PER_TONNE_OF_REPLACED_FERTILISER[Solid_Fuels]	0		
TOTAL_UK_HAFS_FOOD	6875000	Tonne/Year	It is estimated by dividing 1.1 million tonne HaFS food waste by 16% HaFS food waste fraction (WRAP, 2020).
TOTAL_UK_HOUSEHOLD_FOOD	36400000	Tonne/Year	It is estimated by multiplying the 0.543 tonne per person per year food purchase by 67,000,000 UK population.
TOTAL_UK_MANUFACTURE_FOOD	58000000	Tonne/Year	(Parfitt et al., 2016)
TOTAL_UK_PRIMARY_PRODUCTION	50501000	Tonne/Year	(Bajzelj et al., 2019)
TOTAL_UK_RETAIL_FOOD	43275000	Tonne/Year	This is the sum of household and HaFS food purchase in the UK (see TOTAL_UK_HOUSEHOLD_FOOD and TOTAL_UK_HAFS_FOOD)
WASTE_TO_AD_&_COMPOST_CONVERSION_FACTOR	0.659	Dimensionless	We assume that one tonne of food waste can generate 659 kg AD digestate or equal amount of compost (Salemdeeb et al., 2017).
TOTAL_UK_PRIMARY_FOOD_CONSUMPTION	66955400	Tonne/Year	(Audsley et al., 2009; Hess et al., 2015)
WATER_USE_PER_TONNE_OF_HOUSEHOLD	13.3	m^3/Tonne	Average water consumption via kitchen tap in the UK is around 19.8 litre per capita per day or 7.227 m^3 per capita per year (Richter and Stamminger, 2012). Dividing this by 0.543 tonne per capita per year food purchase suggests that the water consumption of UK household in kitchen is 13.31 m^3/tonne of food.

Table A1.13. Energy, Water and Climate Parameters, Values and Data Sources

PARAMETER	VALUE	UNIT	DOCUMENT
AVERAGE_COLLECTION_DISTANCE	20	km	Assumption which is also compatible with (Slorach et al., 2019).
AVERAGE_TRANSPORT_ENERGY_PER_TONNE_KM	0.00042	MWh/ Tonne / km	Based on average laden heavy goods vehicles (BEIS, 2020a).
ENERGY_CONSUMPTION_OF_UK_AGRICULTURE[Electricity]	4205332	MWh/ Year	(BEIS, 2020d)
ENERGY_CONSUMPTION_OF_UK_AGRICULTURE[Natural_Gas]	1077757		
ENERGY_CONSUMPTION_OF_UK_AGRICULTURE[Oil]	10634954		
ENERGY_CONSUMPTION_OF_UK_AGRICULTURE[Solid_Fuels]	1541598		
ENERGY_CONSUMPTION_OF_UK_FOOD_MANUFACTURE[Electricity]	11336535	MWh/ Year	Sum of 'manufacture of food products' and 'manufacture of beverages' in (BEIS, 2020c)
ENERGY_CONSUMPTION_OF_UK_FOOD_MANUFACTURE[Natural_Gas]	20150283		
ENERGY_CONSUMPTION_OF_UK_FOOD_MANUFACTURE[Oil]	1192196		
ENERGY_CONSUMPTION_OF_UK_FOOD_MANUFACTURE[Solid_Fuels]	467113		

ENERGY_CONSUMPTION_OF_UK_HAFS[Electricity]	8650000	MWh/ Year	Sum of catering energy across all sectors in (BEIS, 2020c)
ENERGY_CONSUMPTION_OF_UK_HAFS[Natural_Gas]	6900000		
ENERGY_CONSUMPTION_OF_UK_HAFS[Oil]	9488000		
ENERGY_CONSUMPTION_OF_UK_HAFS[Solid_Fuels]	5775113		
ENERGY_CONSUMPTION_OF_UK_RETAIL[Electricity]	10365700	MWh/ Year	Energy use in the retail sector is extracted from (BEIS, 2020c) and multiplied by an average 40% share of food commodity from the UK retail sale (ONS, 2023). To avoid double counting, the energy use for catering in retail sector is subtracted from the total value.
ENERGY_CONSUMPTION_OF_UK_RETAIL[Natural_Gas]	3576900		
ENERGY_CONSUMPTION_OF_UK_RETAIL[Oil]	749300		
ENERGY_CONSUMPTION_OF_UK_RETAIL[Solid_Fuels]	640100		
ENERGY_INTENSITY_OF_WATER_USE	0.00065	MWh/ m^3	(Majid et al., 2020)
ENERGY_USE_PER_TONNE_OF_REDISTRIBUTION[Electricity]	0.033	MWh/ Tonne	Carbon emission of electricity and oil used by Fareshare for redistributing 6,699 tonne food surplus in 2019-20 was 51.63 and 1108.76 Tonne CO_{2e}, respectively (Byrne et al., 2021). Dividing these by 0.23314 and 0.28484 Tonne CO_{2e}/ MWh UK electricity and diesel emission factors (BEIS, 2020a), it is estimated that the organisation used 221.5 MWh electricity and 3,892.57 MWh oil in total or 0.033 MWh electricity
ENERGY_USE_PER_TONNE_OF_REDISTRIBUTION[Natural_Gas]	0		
ENERGY_USE_PER_TONNE_OF_REDISTRIBUTION[Oil]	0.58		
ENERGY_USE_PER_TONNE_OF_REDISTRIBUTION[Solid_Fuels]	0		

			and 0.58 MWh oil per tonne of redistributed food surplus.
FOOD_PRODUCTS_ROAD_TRANSPORT	49424000000	Tonne *km/ Year	This is the sum of UK annual road transport for "products of agriculture, hunting, and forestry, fish, and other fishing products", and "food products, beverages and tobacco" product groups in 2019 (online data code: ROAD_GO_NA_TGTT) (Eurostat, 2022).
FOOD_SHOPPING_DISTANCE_PER_PERSON	640	km/ Person/ Year	On average, it takes 4.7 trip per week for each household to purchase the household food (DEFRA, 2023a). This means almost 2 trip per person per week (4.7 / 2.4 person/household = 1.96) or 102 trip per person per year. Multiplying it by the average trip length of 3.9 miles or 6.28 km (excluding short walks) (ONS, 2023) suggests that each person in the UK travel around 640 km per year for food shopping.
NET_ELECTRICITY_PER_TONNE_OF_SEWER_TREATMENT	-0.022	MWh/ Tonne	It’s estimated that the Avonmouth AD plant generates 0.036 MWh electricity per tonne of sewer sludge (Geneco, 2020). With an estimated Energy Return on Investment (EROI) of 2.48, the electricity consumption fraction is around 0.0146 MWh/tonne. Hence, the net electricity fraction of AD treatment of sewer is estimated to be -0.0216 MWh/tonne.

NET_ENERGY_PER_TONNE_OF_REPLACED_PIG_FEED	-0.13	MWh/Tonne	The pig feed composition in the UK is composed of Barley (28.4%), Wheat (15.8%), Soya (7%), rapeseed meal (14%), wheat feed (27.5%) and rest (7.3%) (De Menna et al., 2019). Energy use per tonne of each crop (extracted from GFLI (2021)) is then multiplied to the above proportions. The sum is 0.929 MWh per tonne of pig feed. Since one tonne of food waste can replace 130 kg dry or 430 kg animal feed (on average 140 kg) (Salemdeeb et al., 2017), the above energy use per tonne of pig feed is multiplied by -0.14 tonne of food waste/ tonne of animal feed.
PET_FEED_AVOIDED_ENERGY	-2.19	MWh/Tonne	(FEDIAF, 2018) estimated the energy consumption of producing average dog and cat food as following: wet dog food: 4.14 kWh/day; dry dog food: 1.04 kWh/day; wet cat food: 1.31 kWh/day; dry cat food: 0.32 kWh/day. It assumes the average dog eats 1048 g wet or 233 g dry food, and average cat eats 316 g wet or 70 g dry food per day. To estimate energy consumption per unit of feed, corresponding energy consumption rates are divided by average feed consumption rates. After converting the units from kWh/g to MWh/tonne, energy consumption per tonne of feed is estimated as 3.95 MWh/tonne wet dog feed, 4.46 MWh/ tonne dry dog feed, 4.14 MWh/tonne wet cat feed, and 4.56 MWh/tonne dry cat feed. Averaging these by proportion of UK dry-wet feed consumption (ibid), the

			energy footprint of pet feed is estimated to 4.38 MWh/tonne. Finally, assuming that one tonne of wasted food can replace 0.5 tonne of wet and dry feed on average, the above estimate is multiplied by 0.5; hence, the pet feed avoided energy value is 2.19 MWh/tonne food waste.
BLUE_WATER_FOOTPRINT_OF_UK_PRIMARY_PRODUCTION	3520000000	m^3/ Year	(Hess et al., 2015)
FRESHWATER_ABSTRACTION_PER_MWh_ELECTRICITY	0.64	m^3/ MWh	It is estimated by dividing 198,000,000 m^3 freshwater (including surface and groundwater) abstraction by 309.4 TWh UK thermoelectricity generation in 2010 (Byers et al., 2014).
NET_WATER_PER_TONNE_OF_AD	0.2	m^3/ Tonne	Assumption based on Geneco (2020)
NET_WATER_PER_TONNE_OF_COMPOST	0	m^3/ Tonne	No value is reported in relevant LCA literature, most likely due to its insignificance. Hence, we assume the value is zero.
NET_WATER_PER_TONNE_OF_INCINERATION	0.2	m^3/ Tonne	(Tolvik, 2020)
NET_WATER_PER_TONNE_OF_LANDFILL	0.2	m^3/ Tonne	Assumption
NET_WATER_PER_TONNE_OF_SEWER	0.016	m^3/ Tonne	Assumption based on Geneco (2020)

PET_FEED_AVOIDED_WATER	-6.5	m^3/ Tonne	FEDIAF (2018), the same source for the energy and carbon footprint of pet food, suggests an unrealistically high value for water use per tonne of pet food (i.e., 4,053 m^3/tonne). The report itself even warns about the reliability of this estimate. Since there was not any other national and regional estimate, we use a more realistic estimate from a case study of water consumption in canned tuna (pet food) plant in Thailand (Uttamangkabovorn et al., 2005). The 13 m^3/tonne estimate of pet food water usage is then halved as we assumed that one tonne of food surplus can replace 0.5 tonne of dry and wet pet feed.
PIG_FEED_AVOIDED_WATER	-3.76	m^3/ Tonne	The pig feed composition in the UK is composed of Barley (28.4%), Wheat (15.8%), Soya (7%), rapeseed meal (14%), wheat feed (27.5%) and rest (7.3%) (De Menna et al., 2019). Water Consumption per tonne of each crop (extracted from GFLI (2021)) is then multiplied to the above proportions. The sum is 26.83 m^3 per tonne of pig feed. Since one tonne of food waste can replace 130 kg dry or 430 kg animal feed (on average 140 kg) (Salemdeeb et al., 2017), the above energy use per tonne of pig feed is multiplied by -0.14 tonne of food waste/ tonne of animal feed.
WATER_USE_PER_TONNE_OF_HAFS	22.73	m^3/ Tonne	It is estimated by dividing 156,300,000 m^3 water use in HaFS sector (Environment Agency, 2013) by the

			estimated 6,875,000 tonne UK HaFS food.
WATER_USE_PER_TONNE_OF_MANUFACTURE	3.276	m^3/ Tonne	It is estimated by dividing 190,000,000 m^3 UK food and drink manufacturing water use (Environment Agency, 2013) by 58,000,000 tonne UK manufactured food (Parfitt et al., 2016).
WATER_USE_PER_TONNE_OF_RETAIL	0.229	m^3/ Tonne	It is estimated by dividing 9,900,000 m^3 water use in retail and wholesale sector (Environment Agency, 2013) by the estimated 43,275,000 tonne retailed food in the UK.
EMISSION_PER_TONNE_OF_REDISTRIBUTION	0.186	Tonne CO_{2e}/ Tonne	It is estimated by dividing 1,246.87 Tonne CO_{2e} operational emission of Fareshare by 6,699 tonne of food surplus redistributed in 2019-20 (Byrne et al., 2021).
FUELS_EMISSION_FACTOR[Electricity]	0.234	Tonne CO_{2e}/ MWh	The UK conversion factors (BEIS, 2020a) is the main data source for fuel emissions in this study. For electricity, however, we use (BEIS, 2021a), since it provides projection of the emission factor up to 2100. Although there is a discrepancy between two sources, we use the emission factor of 0.234 CO_{2e}/ MWh based on 2018 value of grid average industrial electricity which is identical to the electricity emission factor of the first source.
FUELS_EMISSION_FACTOR[Natural_Gas]	0.20374		
FUELS_EMISSION_FACTOR[Oil]	0.28484		
FUELS_EMISSION_FACTOR[Solid_Fuels]	0.33726		
INCINERATION_NET_EMISSION_FRACTION	0.343	Tonne CO_{2e}/ Tonne	(Tolvik, 2020)
LANDFILL_NET_EMISSION_FRACTION	0.375	Tonne CO_{2e}/ Tonne	(Tolvik, 2020)

NET_EMISSION_PER_TONNE_OF_REPLACED_FERTILISER	-0.021	Tonne CO_{2e}/ Tonne	(Slorach et al., 2019)
PET_FEED_AVOIDED_EMISSION	-0.76	Tonne CO_{2e}/ Tonne	FEDIAF (2018) estimated the CO_{2e} emission of producing average dog and cat food as following: wet dog food: 1.27 kg CO_{2e}/day; dry dog food: 0.382 kg CO_{2e}/day; wet cat food: 0.386 kg CO_{2e}/day; dry cat food: 0.117 kg CO_{2e}/day. It assumes the average dog eats 1,048 g wet or 233 g dry food, and average cat eats 316 g wet or 70 g dry food per day. To estimate the emission per unit of feed, corresponding emission rates are divided by average feed consumption rates. After converting the units from kg CO_{2e}/g to Tonne CO_{2e}/tonne, carbon emission per tonne of feed is estimated as 1.21 Tonne CO_{2e}/tonne wet dog feed, 1.64 Tonne CO_{2e}/ tonne dry dog feed, 1.22 Tonne CO_{2e}/tonne wet cat feed, and 1.67 Tonne CO_{2e}/tonne dry cat feed. Averaging these by proportion of UK dry-wet feed consumption (ibid), the carbon emission of pet feed is estimated to 1.527 Tonne CO_{2e}/tonne. Finally, assuming that 1 tonne of wasted food can replace 0.5 tonne of wet and dry feed on average, the above estimate is multiplied by 0.5; hence, the pet feed avoided emission value is 0.7635 Tonne CO_{2e}/tonne food waste.

PIG_FEED_AVOIDED_EMISSION	-0.12	Tonne CO_{2e}/ Tonne	The pig feed composition in the UK is composed of Barley (28.4%), Wheat (15.8%), Soya (7%), rapeseed meal (14%), wheat feed (27.5%) and rest (7.3%) (De Menna et al., 2019). Carbon emission per tonne of each crop (extracted from GFLI (2021)) is then multiplied to the above proportions. The sum is 0.8463 Tonne CO_{2e} per tonne of pig feed. Since one tonne of food waste can replace 130 kg dry or 430 kg animal feed (on average 140 kg) (Salemdeeb et al., 2017), the above energy use per tonne of pig feed is multiplied by -0.14 tonne of food waste/ tonne of animal feed.
UK_AGRICULTURE_TERRITORIAL_EMISSIONS	62200000	Tonne CO_{2e}/ Year	Sum of agriculture and croplands emission in (BEIS, 2021b)

Table A1.14. Socio-Economic Parameters, Values and Data Sources

PARAMETER	VALUE	UNIT	DOCUMENT
COMMERCIAL_WASTE_COLLECTION_COST	150	£ / Year	Estimated based on Binns and Neil (2023) and Business Waste Company (2023)
COMMERCIAL_FOOD_WASTE_TRANSFER_COST	76	£ / Year	Estimated based on Binns and Neil (2023) and Business Waste Company (2023)
COMMERCIAL_WASTE_TO_INCINERATION_TRANSFER_COST	156	£ / Year	Estimated based on Binns and Neil (2023) and Business Waste Company (2023)

COMMERCIAL_WASTE_TO_LANDFILL_TRANSFER_COST	256	£ / Year	Estimated based on Binns and Neil (2023) and Business Waste Company (2023)
OPERATING_COST_OF_COMPOSTING	14	£ / Year	(Slorach et al., 2019)
CAPITAL_COST_OF_COMPOSTING	4	£ / Year	(Slorach et al., 2019)
COMPOST_PRICE_PER_TONNE_OF_FOOD_WASTE	2.58	£ / Year	Current sale price of compost is Eur 10 (~£8.6) (Gilbert and Siebert, 2022). It is then multiplied by the food waste to Compost conversion factor of 0.3 based on Slorach et al. (2019). The latter source, however, estimated a much smaller value (i.e., 0.23£/tonne of food waste)
AD_GATE_FEES	34	£ / Year	(Boulding and Barker, 2021; WRAP, 2021)
OPERATING_COST_OF_AD	8	£ / Year	Based on (Slorach et al., 2019). Although (Simpson and Scholes, 2020) estimate a cost of 37 £/tonne AD food waste processing it does not provide data for other treatment options. To be consistent, hence, we use the first source.
CAPITAL_COST_OF_AD	7	£ / Year	Based on (Slorach et al., 2019). Although (Simpson and Scholes, 2020) estimate a cost of 37 £/tonne AD food waste processing it does not provide data for other treatment options. To be consistent, hence, we use the first source.
OPERATING_COST_OF_PIG_FEED	8	£ / Year	NO DATA. We assume it is equal to AD operating cost in (Slorach et al., 2019)
CAPITAL_COST_OF_PIG_FEED	7	£ / Year	NO DATA. We assume it is equal to AD capital cost in (Slorach et al., 2019)

TOTAL_UK_AGRICULTURE_OUTPUT	28,690,000,000	£ / Year	Mean value of 5 years from 2017 to 2021 in (DEFRA, 2022a)
PIG_FEED_REPLACEMENT_BENEFIT	35.84	£ / Year	Average pig feed prices from 2017 to 2021 (£256) from (DEFRA, 2023b) which is then multiplied by 0.14 food surplus to pig feed conversion factor based on (Salemdeeb et al., 2017)Click or tap here to enter text..
CAPITAL_COST_OF_INCINERATION	28	£ / Year	(Slorach et al., 2019)
CAPITAL_COST_OF_LANDFILL	12		(Slorach et al., 2019)
CHARGE_PER_CUBIC_METER	1.4	£ / m3	(Wessex Water, 2023)
ENERGY_FROM_WASTE_GATE_FEES	93	£ / Year	(Boulding and Barker, 2021)
FEED_IN_TARIFF_GENERATION_AND_EXPORT_PRICE	135.3	£ / MWh	(Simpson and Scholes, 2020)
UK_HAFS_INTERIM_CONSUMPTION	28,076,000,000	£ / Year	Mean of deflated values for five years minus an estimated 24% alcoholic drinks share of the sector (ONS, 2022)
UK_HAFS_TURNOVER	55,411,000,000	£ / Year	Mean of deflated values for five years minus an estimated 24% alcoholic drinks share of the sector (ONS, 2022)
HOME_COMPOSTING_NET_COST	-19.35	£ / Year	Current sale price of compost for home gardens is Eur 75 (~£65.4) (Gilbert and Siebert, 2022). It is then multiplied by the food waste to Compost conversion factor of 0.3 based on Slorach et al. (2019).
SEPARATE_COLLECTION_AND_DISPOSAL_COST	34	£ / Year	(Boulding and Barker, 2021; WRAP, 2021)

HOUSEHOLD_ENERGY_COST_PER_MWH[Electricity]	160	£ / MWh	Average of five years household electricity bills (~£577) divided by fixed consumption levels of 3.6 MWh per year (Department for Energy Security and Net Zero, 2023a)
HOUSEHOLD_ENERGY_COST_PER_MWH[Natural_Gas]	36.6	£ / MWh	Average of five years household gas bills (~£498) divided by fixed consumption levels of 13.6 MWh per year (Department for Energy Security and Net Zero, 2023b)
HOUSEHOLD_ENERGY_COST_PER_MWH[Oil]	116.5	£ / MWh	Five years average diesel price is 1.27 £/Liter (Department for Energy Security and Net Zero, 2023c) which is then divided by 0.0109 MWh/Liter diesel conversion factor (AEA, 2012).
HOUSEHOLD_ENERGY_COST_PER_MWH[Solid_Fuels]	0	£ / MWh	NA
HOUSEHOLD_PER_CAPITA_FOOD_COST	1420	£ / Person	(DEFRA, 2022b)
PET_FEED_NET_COST	-1300	£ / tonne	Estimated based on (Statista, 2022, 2020) while assuming 1 tonne of food leftover can replace 0.5 tonne of pet feed.
RESIDUAL_COLLECTION_AND_DISPOSAL_COST	214	£/tonne	(Boulding and Barker, 2021; WRAP, 2021)
OPERATING_COST_OF_INCINERATION	26	£ / tonne	(Slorach et al., 2019)
LANDFILL_GATE_FEES	116	£ / tonne	(Boulding and Barker, 2021)
LANDFILL_TAX	91.35	£ / tonne	(Binns and Neil, 2023; Boulding and Barker, 2021)

OPERATING_COST_OF_LANDFILL	5	£ / tonne	(Slorach et al., 2019)
TOTAL_UK_MANUFACTURE_INTERIM_CONSUMPTION	72,516,000,000	£ / Year	Mean of deflated five recent years values based on (ONS 2022)
UK_MANUFACTURE_TURNOVER	103,953,000,000	£ / Year	Mean of deflated five recent years values based on (ONS 2022)
REDISTRIBUTION_COST_PER_TONNE_OF_FOOD	590	£ / Tonne	Estimated based on Fareshare (2023); and WRAP (2022)
REDISTRIBUTION_GVA_PER_TONNE_OF_SURPLUS	434	£ / Tonne	Estimated based on GVA equation from NCVO (2022) and data from Fareshare (2021).
TOTAL_UK_FOOD_RETAIL_INTERIM_CONSUMPTION	93,506,000,000	£ / Year	Mean of deflated five recent years values based on (ONS 2022) multiplied by an estimated 64% share of food and non-alcoholic drink from total retail sales.
UK_RETAIL_TURNOVER	113,164,000,000	£ / Year	Mean of deflated five recent years values based on (ONS 2022) multiplied by an estimated 64% share of food and non-alcoholic drink from total retail sales.
WHOLESALE_ELECTRICITY_PRICE	37	£ / MWh	(Simpson and Scholes, 2020)
REDUCTION_COST_FOR_GOVERNMENT_FRACTION	0.5	dmnl	Estimated based on Hanson and Mitchell (2017)
REDUCTION_COST_FOR_MANUFACTURE_FRACTION	0.25	dmnl	Estimated based on Hanson and Mitchell (2017)
REDUCTION_COST_FOR_RETAIL_FRACTION	0.25	dmnl	Estimated based on Hanson and Mitchell (2017)
INITIAL_PRODUCTION_COST_BENEFIT_RATIO	0.769	dmnl	(Hanson and Mitchell, 2017)

INITIAL_RETAIL_COST_BENEFIT_RATIO	0.196	dmnl	(Hanson and Mitchell, 2017)
INITIAL_MANUFACTURE_COST_BENEFIT_RATIO	0.263	dmnl	(Hanson and Mitchell, 2017)
INITIAL_HOUSEHOLD_COST_BENEFIT_RATIO	0.004	dmnl	(Hanson and Mitchell, 2017
INITIAL_HAFS_COST_BENEFIT_RATIO	0.0588	dmnl	(Hanson and Mitchell, 2017)
WHOLESALE_TO_RETAIL_GVA_RATIO	0.64	dmnl	Contrary to our model, UK agri-food economic reports classify the wholesale as a separate sector to the retail (DEFRA, 2021b). Hence, to include the impact of food waste management on the agri-food economy, we estimated a wholesale to retail GVA ratio based on ONS (2022) and multiply it to the retail GVA to estimate wholesale food GVA.
MEASUREMENT_PERIOD	1	Year	Assumption
VERY_LOW_FOOD_SECURITY_FRACTION	GRAPH(TIME)	Per Year	Graphical values for each simulation year estimated based on (Armstrong et al., 2023b, 2023a, 2022b, 2022a, 2021a, 2021b) as following: (0, 0.08), (1, 0.08), (2, 0.07), (3, 0.1), (4, 0.12), (5, 0.11), (6, 0.1), (7, 0.09), (8, 0.08), (9, 0.08), (10, 0.07), (11, 0.07), (12, 0.07)
LOW_FOOD_SECURITY_FRACTION	GRAPH(TIME)	Per Year	Graphical values for each simulation year estimated based on (Armstrong et al., 2023b, 2023a, 2022b, 2022a, 2021a, 2021b) as following: (0.00, 0.09), (1.00, 0.09), (2.00, 0.08), (3.00, 0.1), (4.00, 0.12), (5.00, 0.11), (6.00, 0.1), (7.00, 0.09), (8.00, 0.09),

			(9.00, 0.09), (10.00, 0.08), (11.00, 0.08), (12.00, 0.08)

Table A1.15. Stock Initial Values

STOCK	VALUE	UNIT	DESCRIPTION
INIT Primary_Production	376090	Tonne	Due to the dominance of goal seeking loops, the stock balances at this value. Assuming the system in equilibrium, this is set as the initial value.
INIT Production_Waste	11960		
INIT Manufacture_Inventory	345150		
INIT Manufacture_Waste	8920		
INIT Retail_Inventory	329450		
INIT Retail_Waste	2290		
INIT HaFS_Food	72820		
INIT HaFS_Waste	11500		
INIT Household_Food	250130		
INIT Household_Waste	45800		
INIT Urban_Population	463405	Person	(ONS, 2020)
INIT Low_Food_Secure_Population	46340	Person	Initial Bristol population multiplied by 10% UK low food security fraction based on Armstrong et al. (2021)
INIT Very_Low_Food_Secure_Population =	32438	Person	Initial Bristol population multiplied by 7% UK very low food security fraction based on Armstrong et al. (2021)
INIT Urban_HaFS_Businesses[Restaurants]	1130	Outlet	WRAP (2013) identifies 9 subsectors for the HaFS sector including restaurants, pubs, education, healthcare, hotels, quick service restaurants, services, leisure, and staff catering. It also accounts for around 14% food waste generated from the
INIT Urban_HaFS_Businesses[Pubs]	53		

INIT Urban_HaFS_Businesses[Education]	258		preparation of ready to serve food items and meals for the HaFS sector at food manufacturing sites. Since 'staff catering' is the smallest subsector and there is no data around it, we integrate it with the manufacturing sites estimated data and label it as 'others'. The data for the number of restaurants, pubs, hotels, and quick service restaurants (total 1,547 businesses) is sourced from Tripadvisor website (Tripadvisor, n.d.), while the data for education and healthcare subsectors is extracted from Bristol Food Hygiene Ratings dataset (Food Standards Agency, 2022). Since there is no data available for the services and leisure outlets, we assume 1% of the estimated outlets in the UK by WRAP (2013) is located in Bristol. This method is consistent with WRAP (2013) methodology for estimating HaFS food surplus and waste. However, the available data on quantity of Bristol HaFS businesses in 2022 indicates that the amount of food demand and generated waste in the Bristol HaFS sector is around 70% higher than the UK average estimated in the report. This is most likely due to the growth in the sector since 2013 on one hand, and the concentration of HaFS businesses in big cities such as Bristol on the other hand. Given that, it is worth emphasising that to the best of our knowledge, there is no evidence-based data with high level of certainty around HaFS food demand, or surplus and waste in municipal, regional, or national levels.
INIT Urban_HaFS_Businesses[Healthcare]	222		
INIT Urban_HaFS_Businesses[Hotels]	195		
INIT Urban_HaFS_Businesses[Quick_Service]	364		
INIT Urban_HaFS_Businesses[Services]	20		
INIT Urban_HaFS_Businesses[Leisure]	93		
INIT Urban_HaFS_Businesses[Others]	340		

Table A1.16. Parameters for Scenario Specification

PARAMETER	VALUE	UNIT	DESCRIPTION
PRODUCTION_REDUCTION_CHANGE_FRACTION	0	Per Year	These variables are used for scenario specification in primary production sector.
PRODUCTION_REDISTRIBUTION_CHANGE_FRACTION	0	Per Year	
PRODUCTION_TO_ANIMAL_FEED_CHANGE_FRACTION	0	Per Year	
PRODUCTION_TO_AD_CHANGE_FRACTION	0	Per Year	
PRODUCTION_TO_COMPOST_CHANGE_FRACTION	0	Per Year	
PRODUCTION_TO_INCINERATION_CHANGE_FRACTION	0	Per Year	
PRODUCTION_TO_LANDFILL_CHANGE_FRACTION	0	Per Year	
MANUFACTURE_REDUCTION_FRACTION	0	Per Year	These variables are used for scenario specification in manufacture sector.
MANUFACTURE_TO_REDISTRIBUTION_CHANGE_FRACTION	0	Per Year	
MANUFACTURE_TO_ANIMAL_FEED_CHANGE_FRACTION	0	Per Year	
MANUFACTURE_TO_AD_CHANGE_FRACTION	0	Per Year	
MANUFACTURE_TO_COMPOST_CHANGE_FRACTION	0	Per Year	
MANUFACTURE_TO_INCINERATION_CHANGE_FRACTION	0	Per Year	
MANUFACTURE_TO_LANDFILL_CHANGE_FRACTION	0	Per Year	
RETAIL_REDUCTION_FRACTION	0	Per Year	These variables are used for scenario specification in retail sector.
RETAIL_TO_REDISTRIBUTION_CHANGE_FRACTION	0	Per Year	
RETAIL_TO_ANIMAL_FEED_CHANGE_FRACTION	0	Per Year	
RETAIL_TO_AD_CHANGE_FRACTION	0	Per Year	

RETAIL_TO_COMPOST_CHANGE_FRACTION	0	Per Year	
RETAIL_TO_INCINERATION_CHANGE_FRACTION	0	Per Year	
RETAIL_TO_LANDFILL_CHANGE_FRACTION	0	Per Year	
HAFS_REDUCTION_FRACTION	0	Per Year	These variables are used for scenario specification in HaFS sector.
HAFS_TO_REDISTRIBUTION_CHANGE_FRACTION	0	Per Year	
HAFS_TO_AD_CHANGE_FRACTION	0	Per Year	
HAFS_TO_COMPOST_CHANGE_FRACTION	0	Per Year	
HAFS_TO_INCINERATION_CHANGE_FRACTION	0	Per Year	
HAFS_TO_LANDFILL_CHANGE_FRACTION	0	Per Year	
URBAN_FARMING_TO_HAFS_CHANGE_FRACTION	0	Per Year	
HOUSEHOLD_REDUCTION_FRACTION	0	Per Year	These variables are used for scenario specification in household sector.
HOUSEHOLD_TO_ANIMAL_FEED_CHANGE_FRACTION	0	Per Year	
HOUSEHOLD_TO_AD_CHANGE_FRACTION	0	Per Year	
HOUSEHOLD_COMPOSTING_CHANGE_FRACTION	0	Per Year	
HOUSEHOLD_TO_INCINERATION_CHANGE_FRACTION	0	Per Year	
HOUSEHOLD_TO_LANDFILL_CHANGE_FRACTION	0	Per Year	
URBAN_FARMING_TO_HH_CHANGE_FRACTION	0	Per Year	
HAFS_GROWTH_INACTIVATION	0	Dimensionless	These are inactivation keys for specifying scenarios with (if 1) and without (if 0) growth.
POPULATION_GROWTH_INACTIVATION	0	Dimensionless	

Appendix 2. Costs and Benefits of Food Waste Management

Table A2.1. Costs and benefits of food waste management in Bristol

Costs and benefits of treating 15,500 tonnes of household food waste (unit: £)				
Measure	**Impact on**	**Cost**	**Benefit**	**Net**
Reduction	household	-	40.4 million less food purchase +2.2 million less energy and water use + 1.3 million less waste collection and treatment	~ 44 million
	agri-food economy	11.6 million loss in wholesale and retail GVA +9.1 million loss in manufacture GVA +3.4 million loss in primary production GVA +0.7 million loss in waste management sector GVA +0.2 million cost of government and non-government initiatives	5.8 million re-spending of savings in wholesale and retail +9.1 million more export/ less import manufacture +3.4 million more export/ less import in primary production +0.7 million less gate fees charged to local authority	~ -6 million
Animal Feed	household	-	21.4 million less pet feed purchase	~ 21.4 million
	agri-food economy	0.7 million loss in waste management sector GVA +? Loss in feed sector GVA (out of scope of study)	0.7 million less gate fees charged to local authority	~ 0

Anaerobic Digestion	household	-	0.8 million less waste collection and treatment	~ 0.8 million
	agri-food economy	-	0.2 million less gate fees charged to local authority +0.5 million added value of food waste treatment	~ 0.7 million
Compost	household	-	1.6 million less compost purchase	~ 1.6 million
	agri-food economy	0.7 million loss in waste management sector GVA	0.7 million less gate fees charged to local authority	~ 0
Incineration	household	2 million more waste collection and treatment	-	~ -2 million
	agri-food economy	0.7 million more gate fees charged to local authority	0.7 million added value of food waste treatment	~ 0
Landfill	household	2 million more waste collection and treatment	-	~ -2 million
	agri-food economy	1.1 million more gate fees for local authority +0.3 million loss in waste management sector GVA	-	~ -1.4 million
Costs and benefits of treating 5000 tonnes of Hospitality and Food Service (HaFS) food waste (unit: £)				
Measure	**Impact on**	**Cost**	**Benefit**	**Net**
Reduction	HaFS	7.2 million cost of food waste reduction initiatives	50 million more revenue +1.5 million less waste collection and treatment	~ 44.3 million
	agri-food economy	3.7 million loss in wholesale and retail GVA	44.3 million added value to HaFS sector	~ 41.8 million

		+2.9 million loss in manufacture GVA +1.1 million loss in primary production GVA +0.7 million loss in waste management sector GVA	+1.9 million re-spending of savings in wholesale and retail +2.9 million more export/ less import in manufacture +1.1 million more export/ less import in primary production	
Redistribution	HaFS	-	1.5 million less waste collection and treatment	~ 1.5 million
	agri-food economy	3 million cost of redistribution charities +3.7 million loss in wholesale and retail GVA +2.9 million loss in manufacture GVA +1.1 million loss in primary production GVA +0.7 million loss in waste management sector GVA	2.2 million added value of redistribution charities +13.2 million retail value of redistributed food to households +1.9 million re-spending of savings in wholesale and retail +2.9 million more export/ less import in manufacture +1.1 million more export/ less import in primary production +1.5 million added value in HaFS due to less waste collection and treatment	~ 11.3 million
Anaerobic Digestion	HaFS	-	0.35 million less waste collection and treatment	~ 0.4 million
	agri-food economy	-	0.25 million added value of food waste treatment	~ 0.3 million
Compost	HaFS	-	0.35 million less waste collection and treatment	~ 0.4 million

	agri-food economy	17 thousand loss in total waste management	-	~ 0
Incineration	HaFS	50 thousand more waste collection and treatment	-	~ -0.1 million
	agri-food economy	-	6 thousand added value of food waste treatment	~ 0
Landfill	HaFS	0.55 million more waste collection and treatment	-	~ -0.6 million
	agri-food economy	0.4 million loss in total waste management	-	~ -0.4 million
Costs and benefits of treating 1000 tonnes of retail food waste (unit: £)				
Measure	**Impact on**	**Cost**	**Benefit**	**Net**
Reduction	retail	0.9 million cost of food waste reduction initiatives	2.6 million more revenue +0.24 million less waste collection and treatment	~ 1.9 million
	agri-food economy	0.5 million loss in manufacture GVA +0.2 million loss in primary production GVA +0.1 million loss in waste management sector GVA	1.9 million added value to the retail sector +0.5 million more export/ less import in manufacture +0.2 million more export/ less import in primary production	~ 1.8 million
Redistribution	retail	-	0.24 million less waste collection and treatment	~ 0.2 million
	agri-food economy	0.6 million cost of redistribution charities +0.5 million loss in wholesale and retail GVA	0.4 million added value of redistribution charities +2.6 million retail value of redistributed food to households	~ 2.3 million

		+0.5 million loss in manufacture GVA +0.2 million loss in primary production GVA +0.1 million loss in waste management sector GVA	+0.3 million re-spending of savings in wholesale and retail +0.5 million more export/ less import manufacture +0.2 million more export/ less import in primary production +0.24 million added value in retail due to less waste collection and treatment	
Animal Feed	retail	-	0.24 million less waste collection and treatment	~ 0.2 million
	agri-food economy	-	0.34 million added value of food waste treatment	~ 0.3 million
Anaerobic Digestion	retail	-	18 thousand less waste collection and treatment	~ 0
	agri-food economy	-	25 thousand added value of food waste treatment	~ 0
Compost	retail	-	18 thousand less waste collection and treatment	~ 0
	agri-food economy	28 thousand loss in total waste management	-	~ 0
Incineration	retail	62 thousand more waste collection and treatment	-	~ -0.1 million
	agri-food economy	75 thousand loss in total waste management	-	~ -0.1 million
Landfill	retail	0.16 million more waste collection and treatment	-	~ -0.2 million

	agri-food economy	0.23 million loss in total waste management	-	~ -0.2 million
Costs and benefits of treating 3900 tonnes of manufacture food waste (unit: £)				
Measure	**Impact on**	**Cost**	**Benefit**	**Net**
Reduction	manufacture	9.9 million cost of food waste reduction initiatives	6.9 million more revenue +1 million less waste collection and treatment	~ -1.9 million
	agri-food economy	1.9 million loss in manufacture GVA +0.7 million loss in primary production GVA +0.5 million loss in waste management sector GVA	0.7 million more exports/ less import in primary production	~ -2.4 million
Redistribution	manufacture	-	1 million less waste collection and treatment	~ 1 million
	agri-food economy	2.3 million cost of redistribution charities +2.9 million loss in wholesale and retail GVA +2.3 million loss in manufacture GVA +0.9 million loss in primary production GVA +0.5 million loss in waste management sector GVA	1.7 million added value of redistribution charities +10.1 million retail value of redistributed food to households +1.5 million re-spending of savings in wholesale and retail +2.3 million more export/ less import manufacture +0.9 million more export/ less import in primary production +1 million added value in manufacture due to	~ 8.6 million

			less waste collection and treatment	
Animal Feed	manufacture	-	1 million less waste collection and treatment	~ 1 million
	agri-food economy	-	0.75 million added value of food waste treatment	~ 0.8 million
Anaerobic Digestion	manufacture	-	0.13 million less waste collection and treatment	~ 0.1 million
	agri-food economy	-	87 thousand added value of food waste treatment	~ 0.1 million
Compost	manufacture	-	0.13 million less waste collection and treatment	~ 0.1 million
	agri-food economy	-0.12 million loss in total waste management	-	~ -0.1 million
Incineration	manufacture	0.18 million more waste collection and treatment	-	~ -0.2 million
	agri-food economy	0.1 million loss in total waste management	-	~ -0.1 million
Landfill	manufacture	0.57 million more waste collection and treatment	-	~ -0.6 million
	agri-food economy	0.44 million loss in total waste management	-	~ -0.4 million
Costs and benefits of treating 5200 tonnes of primary production food waste (unit: £)				
Measure	**Impact on**	**Cost**	**Benefit**	**Net**
Reduction	primary production	5.9 million cost of food waste reduction initiatives	2.9 million more revenue +0.4 million less waste collection and treatment	~ -2.6 million

	agri-food economy	2.6 million loss in primary production GVA +0.2 million loss in waste management sector GVA	-	~ -2.8 million
Redistribution	primary production	-	0.4 million less waste collection and treatment	~ 1 million
	agri-food economy	3.1 million cost of redistribution charities +3.9 million loss in wholesale and retail GVA +3 million loss in manufacture GVA +1.1 million loss in primary production GVA +0.2 million loss in waste management sector GVA	2.3 million added value of redistribution charities +13.6 million retail value of redistributed food to households +2 million re-spending of savings in wholesale and retail +3 million more export/ less import manufacture +1.1 million more export/ less import in primary production +0.4 million added value in primary production due to less waste collection and treatment	~ 11.1 million
Animal Feed	primary production	-	0.43 million less waste collection and treatment	~ 0.4 million
	agri-food economy	-	0.57 million added value of food waste treatment	~ 0.6 million
Anaerobic Digestion	primary production	0.74 million more waste collection and treatment	-	~ -0.7 million
	agri-food economy	0.32 million loss in total waste management	-	~ -0.3 million

Compost	primary production	-	0.35 million less waste collection and treatment	~ 0.4 million
	agri-food economy	-	0.16 million added value of food waste treatment	~ 0.2 million
Incineration	primary production	1.16 million more waste collection and treatment	-	~ -1.2 million
	agri-food economy	0.57 million loss in total waste management	-	~ -0.6 million
Landfill	primary production	1.68 million more waste collection and treatment	-	~ -1.7 million
	agri-food economy	1.03 million loss in total waste management	-	~ -1 million

Appendix 3. Validation: Building Confidence in Usefulness of the Model

Given that a model is a simplified representation of the reality, assessing how the behaviour of a simulation model is representative of the behaviour of the observed system is an ongoing debate among epistemologists and modellers. Philosophers and scientists alike assert that that models should be assessed based on their fitness or adequacy for their specific purposes (Parker, 2020). Exploring the model validation in system dynamics field, Barlas (1996) argues that model validity cannot be defined in isolation from the model's purpose, hence a model should be assessed based on its 'usefulness with respect to some purpose'.

While there is no method to 'prove' that a model is correct, there are various tests that enable comparing models against empirical evidence and detect potential deficiencies and limitations of the model (Forrester and Senge, 1980). Although as illustrated in Parsa et al. (2023), model testing is formally placed as a step of dynamics modelling between model development and policy analysis, in practice, it is a process which exist in every stage of modelling (Barlas, 1996). This means the confidence accumulates gradually as the model passes different tests in an iterative process (Forrester and Senge, 1980; Sterman, 2000).

In system dynamics literature, there are a wide variety of validation tests to identify the flaws and limitations of a model. To narrow it down to the most important tests, Pruyt (2013, p.89) raises four guiding questions for testing a model: *"(i) Are the boundaries, structures and parameters adequate? (ii) Does the model allow to generate the behaviours it should be able to generate for the right reasons? (iii) Does the model generate plausible behaviours under extreme conditions? (iv) Does the sensitivity of* *the model to changes in parameters, functions, boundaries, et cetera correspond to the sensitivity of the real system to corresponding changes?".*

For a formal validation of the food waste dynamics model, we provide clarification on boundary adequacy and structure assessment, an extreme conditions test and a sensitivity analysis in the following sections. These correspond to the Pruyt's (2013) first, third, and fourth questions, respectively. The second question which addresses an essential modelling requirement (i.e., a system dynamics model must generate *"the right output behaviour for the right reasons"* (Barlas, 1996)), has been extensively discussed in Results and Discussion section of the main paper and in Parsa et al. (2023). It is important to emphasise that the purpose of these tests is not only to present evidence for validity of the model but to reflect the limitations of the model. In addition to justifying 'why', it is crucial to discuss 'to what extent' one can be confident in the usefulness of the model.

Moreover, it is important to mention that there are plenty of tests (e.g., 17 tests are discussed in Forrester & Senge (1980) and 12 in Sterman (2000)), which often take place in an iterative loop during the model development and application. It is neither intended, nor possible to apply a comprehensive list of tests –as such a list does not exist– to validate the model developed in this study. Most of the validation tests in the food waste dynamics model have been already conducted directly or indirectly during the iterative model building process and addressed 'informally' either in the results or in the documentations. For instance, dimensional consistency asks whether each equation is dimensionally consistent without the use of parameters having no real world meaning (Sterman, 2000). Such a test has been an essential principle during quantitative modelling process and is well-documented in the Appendix 1 of this

Supplementary Materials. The same applies to parameter assessment test. Similarly, integration error test is to ensure that the results are not sensitive to the choice of time step or numerical integration method (Sterman, 2000). Although not formally reported, the integration error test is assumed to be an integral part of the modelling and is conducted thoroughly during the modelling phase of this study. Hence, focusing on some of the most important tests in this section is only towards a 'formal validation' of the model.

Before getting into the validation tests, it is essential to repeat the 'purpose' of the food waste dynamics model in this study. Without a well-defined purpose of the model application, any debate over the merit of model compared to others is often irresolvable (Forrester and Senge, 1980). One useful approach to the purpose of simulation models is to distinguish between three modelling modes: prediction, explanation, and exploration (Desjardins et al., 2020). While predictive modelling aims to determine the future state of a system, and explanatory modelling seeks to investigate why or how the system came to be in known state, exploratory modelling is not interested in a specific final state of the system, but in various future states which are caused by hypothetical changes in the model configurations (Desjardins et al., 2020).

As stated, the purpose of the dynamic modelling in this study is to 'explore' the food waste impacts on environmental, and socio-economic pillars of sustainable development. This means the model is aimed neither at predicting the precise trend and quantity of urban food waste impacts in the future, nor at explaining its root causes in the status quo. In contrast, the model is designed to explore the changes in environmental and socio-economic impacts of food system as a result of changes in urban food waste management behaviour. Hence, the purpose of the following validation tests is to assess why and to what extent the model is useful to 'explore' the impacts of different food waste management options and policies in urban circular economies.

A3.1. Boundary Adequacy and Structure Assessment

The overall objective of the boundary adequacy test is to make sure if the boundary of the model is large enough to endogenously capture the problem at hand (Pruyt, 2013). The modeller is expected to use literature (e.g., literature review and archival materials) and/or participatory activities (e.g., interviews and workshops) to check the appropriateness of the model boundary, and to clearly define the boundary through different types of diagrams (Sterman, 2000). For the structure assessment test, the modeller should use similar tools and procedures to check whether the structure of the model conform to the real system and laws of nature (Pruyt, 2013; Sterman, 2000). Instead of testing, this section reflects on the process of defining the boundary and structure of the model and its associated limitations.

Setting an inclusive boundary and a conforming structure for the model has been a critical task throughout this research. The model boundary and structure are grounded on a systematic literature review (Parsa et al., 2021) and a multi-stage group model building process (Parsa et al., 2023). To give an example of the process, it is useful to look at the initial workshops during the group model building process, as detailed in Parsa et al. (2023). The workshops with participants from food, energy and water sectors in Bristol were fruitful to identify the key variables in the food, energy, water, and climate (FEWC) system. Initially, the participants identified 99 variables/ topics which were then clustered under 8 food, 8 energy and 8 water titles. After re-clustering the cards and omitting the duplications, 44 topics under 9 titles were identified relevant to the Bristol food (and food waste) system which are used during the system dynamics model building process (Table A3.1). The topics, although not entirely used in the model, provided grounds for developing a detailed SDM which accounts for food (waste) impacts in the context of FEWC nexus.

Table A3.1. Interrelations between food, energy, and water sectors in Bristol food (waste) system.

No.	Title/ Cluster	Topics/ Variables
1	Governance	Financing/ Investment
		Food Regulation/ Government Policy/ Department Lead
		Lack of Linking-up in Large Organisations
2	Behaviour Change	Consumers (e.g., Restaurants)/ Knowledge
		Changes in Behaviour to Eat Seasonally
		Food, Energy, Water Waste Reduction/ Reduced Demand in Food
		More Direct Solutions for Reducing CO_2
		Raising Awareness/ People Make Choices on Food Depending on Energy, CO_2 (e.g., Vegetarian, Local Food)
3	Food Growing Inputs	Sustainable Urban Drainage and Food
		Use of Heat and Gas from Processing Plants
		Poor Understanding of Energy for Agriculture & CO2e Emissions
		Water Usage for Food Growing
		Irrigation/ Additional Watering of Food Crops Grown Locally
		Energy to Pump Water
4	Food Preparation	Kitchen Operation (i.e., Excess Use of Burners)
		Water and Energy Use of Food Preparation from Scratch at Household
		Water and Food Waste of Commercial Food Preparation
		Water and Energy Efficiency of Commercial Food Preparation
		Cooling and Cooking Energy for Food Preparation and Storage
		Smart Refrigeration to Flexible Demand to Suit Renewables Output
		Energy Used for Food and Food Waste Transportation
5		Energy for Food Processing
		Energy Recyclable from Packaging

	Food Processing/ Packaging	Water Use by Food and Energy Manufacture
6	Food Waste and Sewage to AD	Food Waste and Sewage Sludge as Source of Biomethane
		Generating Electricity from AD at Times of Peak Demand to Reduce CO_2 Emissions
		Wastewater from Food Factories Used to Make Biogas
		Energy Used to Treat Wastewater
		Water Use for Food Waste and Sewage Transport
		Sewage Infrastructure to Transport Food Waste
7	Waste to Energy	Gasification and Biodiesel
		Energy from Waste (Pyrolysis) Plant
		Collection of Used Cooking Oil from Homes and Businesses for Production of Biodiesel
8	Nutrient Recovery via Water	Treated Sewage Sludge to Farmland (e.g., Fertiliser Replacement)
		Phosphorous Capture from Digester Outputs
		Energy Efficient Phosphate Extraction for Food Growing
		Digestate to Compost
		Healthy Soils
9	Pollution from Food Sector	Water Contamination from Food Chain
		Water Quality Constraints from Other Sectors
		Impact of Water Pollution on Restriction on Development and Food Production and Inefficient Use of Land
		Impact of Fertilisers and Pesticides in Food Production on Water
		Fish Farm Pollution
		Impact of Food Packaging on Water (e.g., Waste Plastics)

Setting the boundary and structure of the model has been an iterative process informed by the participatory activities and extensive literature review. The resulting model, however, by no means provides a comprehensive representation of the environmental and socio-economic impacts of urban food and food waste. For example, the impact of food production on water pollution and eutrophication or the impact of food packaging on the FEWC nexus are important environmental aspects which are deliberately excluded from the model. Similarly, the boundary for social impacts of the food surplus and waste can be defined much wider than the food insecurity indicator which is addressed in this study.

Aiming for a comprehensive model boundary and structure to represent all the elements and dynamics within the real system is neither possible nor desirable. Given that models are simplified representation of the complexities in the real system, the aim of a system dynamics modeller is to provide useful policy advice by using small models (Pruyt, 2013). As reported in this study, the key policy recommendation of this study is that food waste reduction at consumer sectors and surplus redistribution at supply sectors are the most preferable options for environment, society and economy. Referring to the extensive description and documentation of the model in both studies, it is believed that the policy recommendations of the model will still hold if the boundary further extends.

A3.2. Extreme Conditions Test Applied

A robust model is a model which behaves appropriately in extreme conditions. Testing the model behaviour under extreme conditions can be carried out by direct inspection of the equations and/ or by simulation (Sterman, 2000). The dynamics model in this study has been tested frequently during the model development process. To illustrate one example, the model is tested for an extreme food waste reduction target of 50% per year (Figure A3.1). Although a 50% food waste reduction per year is not possible in real world conditions, the following scenarios are simulated to illustrate the behaviour of the model in such an extreme rate.

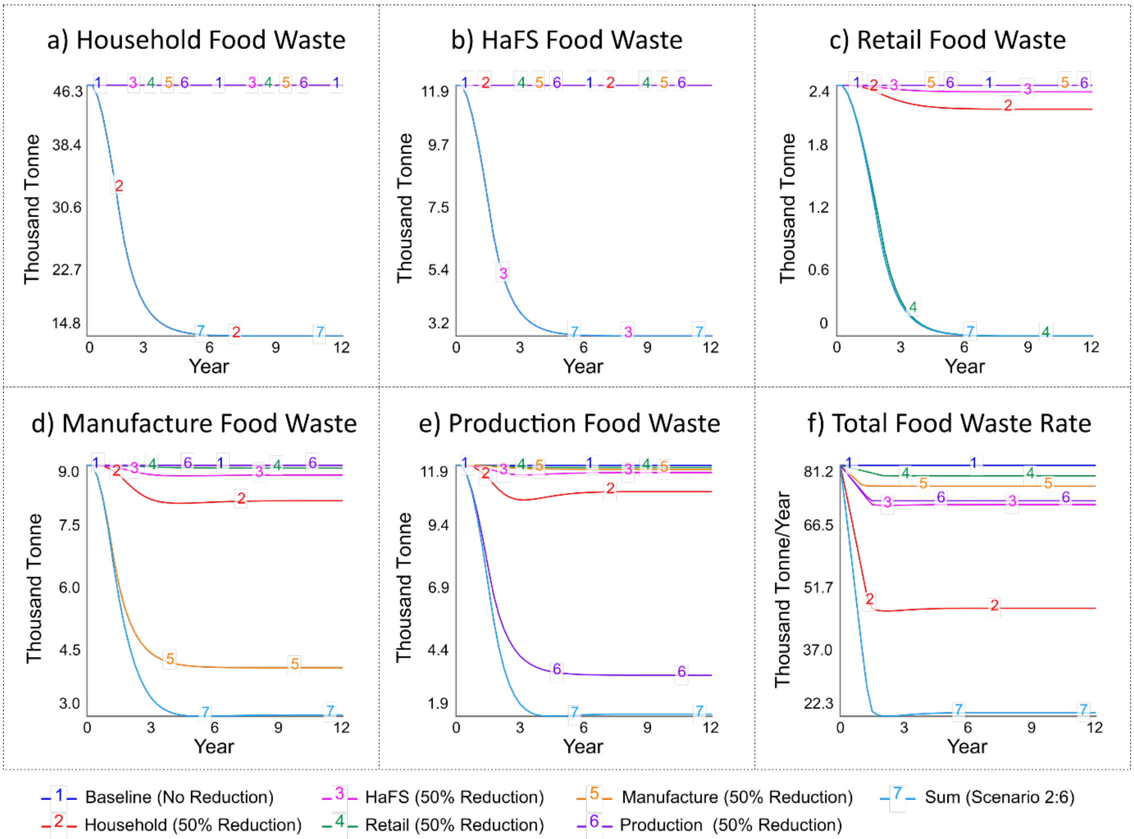

Figure A3.1. Extreme conditions test of the food waste dynamics model to explore the behaviour of stock variables (a, b, c, d, and e) and total food waste rate (f) in response to a 50% annual food waste reduction in agri-food sectors.

The purpose of this test is to illustrate the behaviour of the food waste stocks and flows of the model in extreme scenarios. As Sterman (2000) states, the values of inventories (i.e., food waste stocks in this model) can never drop below zero even if the input is zero and the output has the maximum possible value. The above example examines this aspect of the model and illustrates that food waste stocks/ inventories in the model do not drop below zero in an extreme condition where annually 50% of the food waste is reduced and the remaining food waste is sent for treatment (Figure A3.1a,b,c,d,e). Although the avoidable food waste inflow rate in each scenario reaches zero after two years, the stock acts as a shock-absorber and drops more gradually (Figure A3.1: f vs. a,b,c,d,e). In the retail sector (Figure A3.1c), as it is assumed that all of food waste is avoidable (WRAP, 2020), the food waste stock eventually drops to zero, but does not fall below the zero. This is one example of the model's realistic behaviour in extreme conditions and an illustration of passing the extreme conditions test.

A3.3. Sensitivity Analysis Applied

Sensitivity analysis is an important test to compute the robustness of a model's conclusions in response to changes in uncertain assumptions including model's parameters and equations (Sterman, 2000). To analyse the sensitivity of the model findings, it is fruitful to explore whether the policy recommendations of this study are sensitive to population and HaFS growth rate parameters. Although the assumed 0.6% population and 1.5% HaFS growth rates in this study are estimated based on reliable sources (BCC, 2020; ONS, 2020; Parry et al., 2020), the forecasts are obviously subject to uncertainty. Moreover, the policy recommendations of this study are aimed at urban CEs (i.e., not only Bristol) with different rates of population and economic growths. Thus, a sensitivity analysis of these parameters can help to examine whether the key findings of the model (i.e., preferability of reduction in consumer sectors and redistribution in supply sectors) are sensitive to the growth rate assumptions.

For this sensitivity analysis (Figure A3.2), three different values are assigned to population and HaFS growth rate parameters each: +0.6%, 0%, and -0.6% growth rate for the population and +1.5%, 0%, and -1.5% growth rate for the HaFS sector. To avoid unnecessary complications, both growth rates are set to change simultaneously from positive (Scenario 1, 2 and 7, 8), to zero (Scenario 3, 4 and 9, 10), and then to negative values (Scenario 5, 6 and 11, 12). The purpose of first sensitivity analysis (Figure A3.2a) is to examine if food waste reduction at consumer sectors is the most preferable option (i.e., environmentally, socially, and economically) regardless of the population and HaFS growth rates. For this, a 2.8% annual food waste reduction (Scenario 1, 3 and 5) is compared to the same amount increase in AD treatment (Scenario 2, 4 and 6) at household. The second sensitivity analysis (Figure A3.2b) examines if food waste redistribution at supply sectors is the most preferable option for all of the growth scenarios. This second set of scenarios (Figure A3.2b) compares 3.6% increase in redistribution (Scenario 7, 9 and 11) to 3.6% increase in animal feed (Scenario 8, 10 and 12) in primary production sector.

As the results of sensitivity analysis in the household scenarios (Figure A3.2a) show, food waste reduction (Scenario 1) has lower FEWC footprints compared to the AD increase (Scenario 2) if urban population and HaFS grows. This is what reported in detail in Parsa et al. (2023). The reduction scenario (Scenario 1) also decreased the agri-food GVA, and household costs compared to AD (Scenario 2), as discussed in this paper. What this sensitivity analysis reveals is that similar trends can be seen when growth rates are zero or negative. Reduction, when the growth rates are assumed zero (Scenario 3) or negative (Scenario 5) has consistently lower FEWC footprints, GVA, and costs compared to AD scenarios (Scenario 4 and 6), respectively. Moreover, the trend of each pair of scenario lines for positive growth (Scenario 1 and 2), zero growth (Scenario 3 and 4), and negative growth (Scenario 5 and 6) show identical patterns.

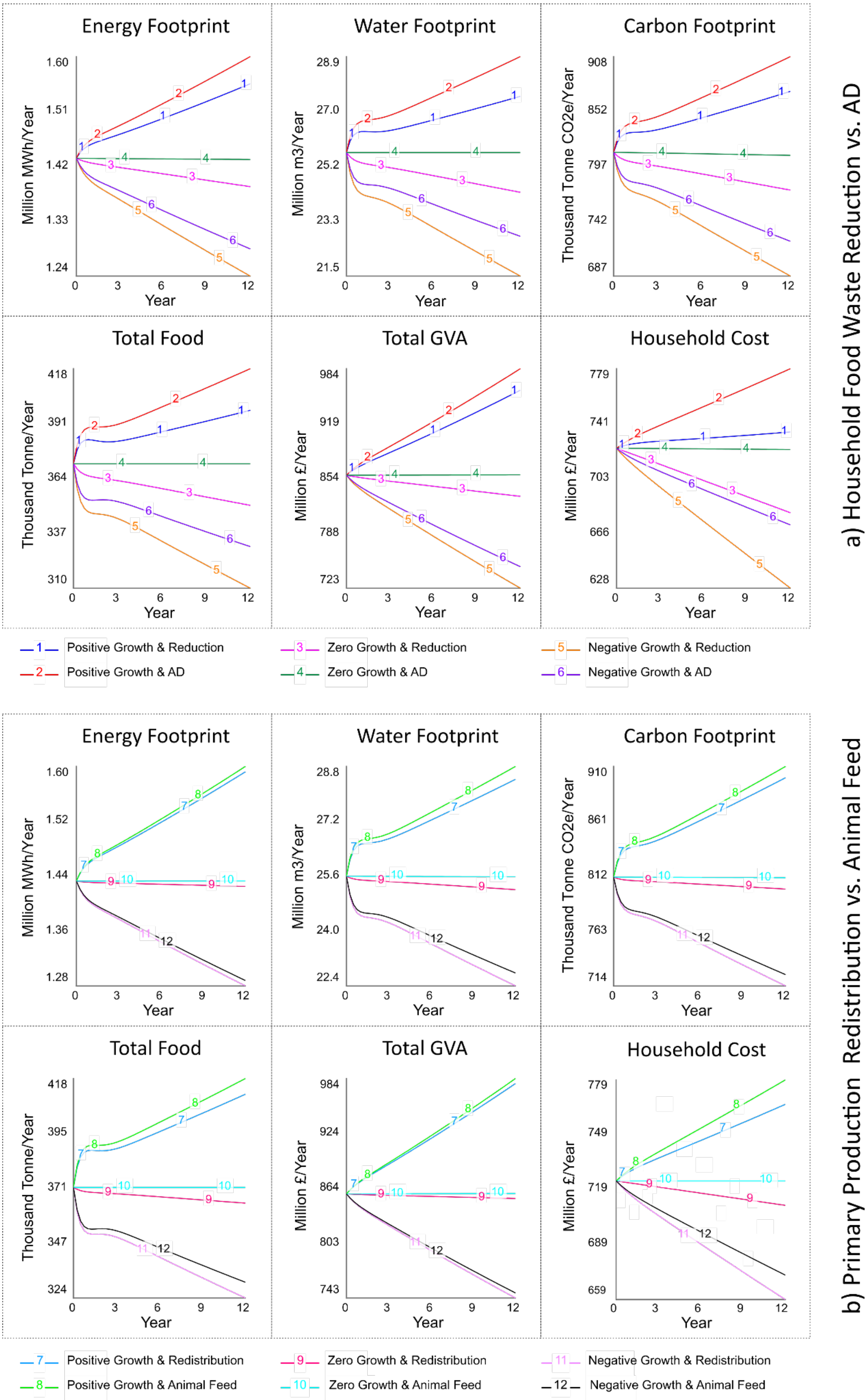

Figure A3.2. sensitivity analysis of key model conclusions.

Figure A3.2b illustrates similar pair of three growth scenarios for increased redistribution versus increased animal feed options in primary production sector. Due to the lower amount of food waste in primary production as well as lower economic and environmental impact of each tonne of food waste at this sector compared to the household, the divergence between each pair of growth scenarios (i.e., Scenario 7 vs. 8; 9 vs. 10; and 11 vs. 12) are not as high as household scenarios. Nevertheless, the scenarios (Scenario 7 to 12) confirm the patterns expressed above and indicate that redistribution is a more preferrable option than animal feed, regardless of the urban population and/ or HaFS growth rate.

A further detailed analysis of the dynamics in Figure A3.2 is out of scope of this sensitivity analysis. The shape and behaviour of the trendlines in each scenario are explained in Parsa et al. (2023) and the main text of the current study. The main text also discusses why reduction and redistribution scenarios are recognised as most favourable economic options when they have a negative impact on the GVA. The purpose of this sensitivity analysis was to test whether these key findings and policy recommendation of this study are applicable to a variety of urban circular economies with different growth rates. As the examples of household and primary production sectors illustrate, the policy recommendations of this study are not sensitive to the growth rate assumptions.

A3.4. Concluding Remarks of Model Validation

As described, the purpose of model validation is to discuss why and to what extent one can trust on the usefulness of the dynamics model presented in this study. Model validation, in this context, is aimed to establish ‘legitimacy’ (and not ‘truth’) by testing the model to ensure it does not contain known or detectable flaws.

In addition to the informal tests which were conducted during the modelling process, this validation discussion provided some clarification on the model boundary and structure and reported the results of an extreme conditions test and a sensitivity analysis. Overall, the results of these tests did not identify any flaws in the model that contradict the key findings and policy recommendations of the study. The test results also suggest that the modelling conclusions are applicable to other urban CEs with different food demand rates as illustrated in the sensitivity analysis. This validation discussion also provided the opportunity to reflect on the limitations of the model which are addressed above as well as the limitation section in the main text (Section 4.6).

All in all, it is important to mention that the discussion on model validation and research limitations in this section is not the only effort towards building trust to the model findings. The detailed reporting of modelling process, assumptions, and results in this document is explicitly towards enhancing transparency and facilitating the replicability and reproducibility of the model. As discussed in Parsa et al. (2023), adopting a group model building approach and engaging the FEW experts and stakeholders in the modelling process was also a critical step in building trust in the model among practitioners and policy makers. Thus, this formal validation section was another effort to boost the confidence in the model and showcase its usefulness while acknowledging the limitations of the study.

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