Appendices

Appendix 1: Diagrammatic and Tabular Summary of Conceptual Frameworks Linking Agriculture and Food Security Outcomes

Appendix 1.1 High-level diagrammatic illustrations of the interlinked nature of agriculture systems and food and nutrition security

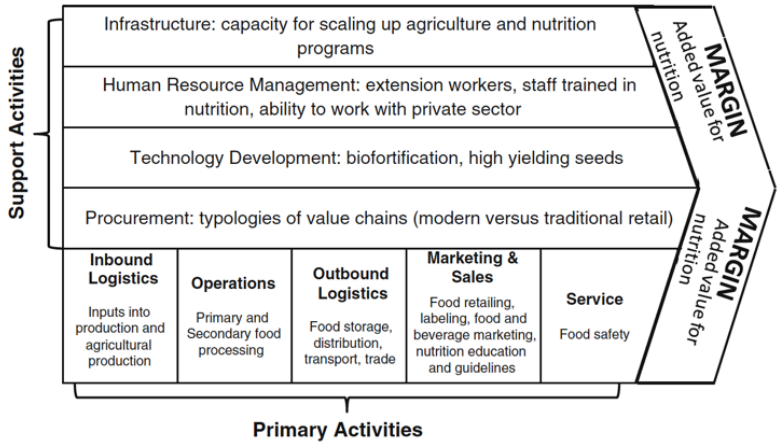


Figure A1: Nutrition-focused food value chain framework (Fanzo, et al., 2017: 765)

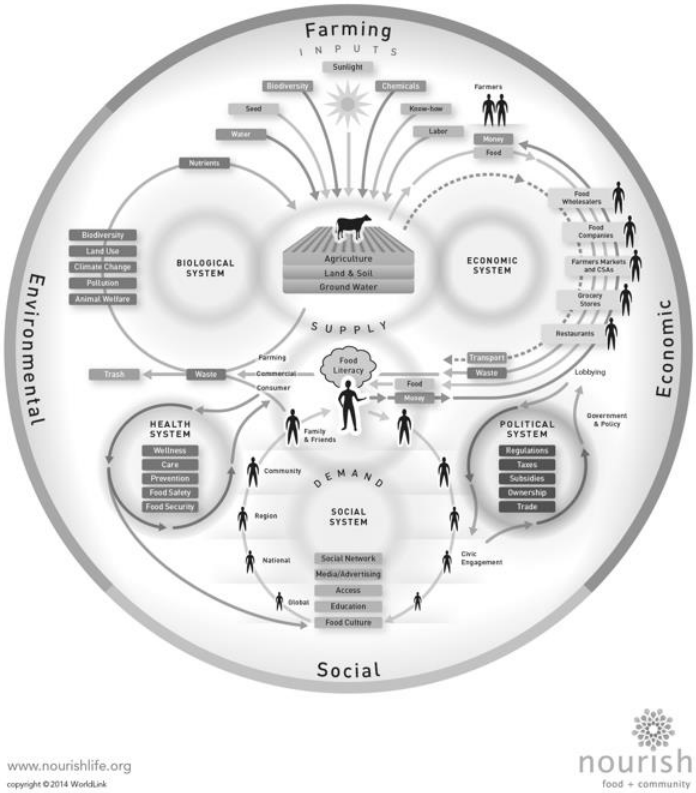


Figure A2: Nourish Food System Map (www.nourishlife.org in Neff & Lawrence, 2015: 4) copyright © 2014 WorldLink

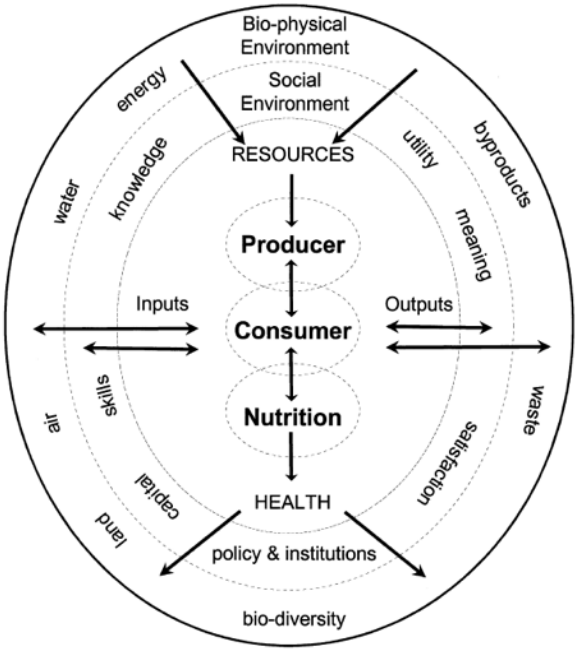


Figure A3: The food and nutrition system (Sobal, et al., 1998: 857)

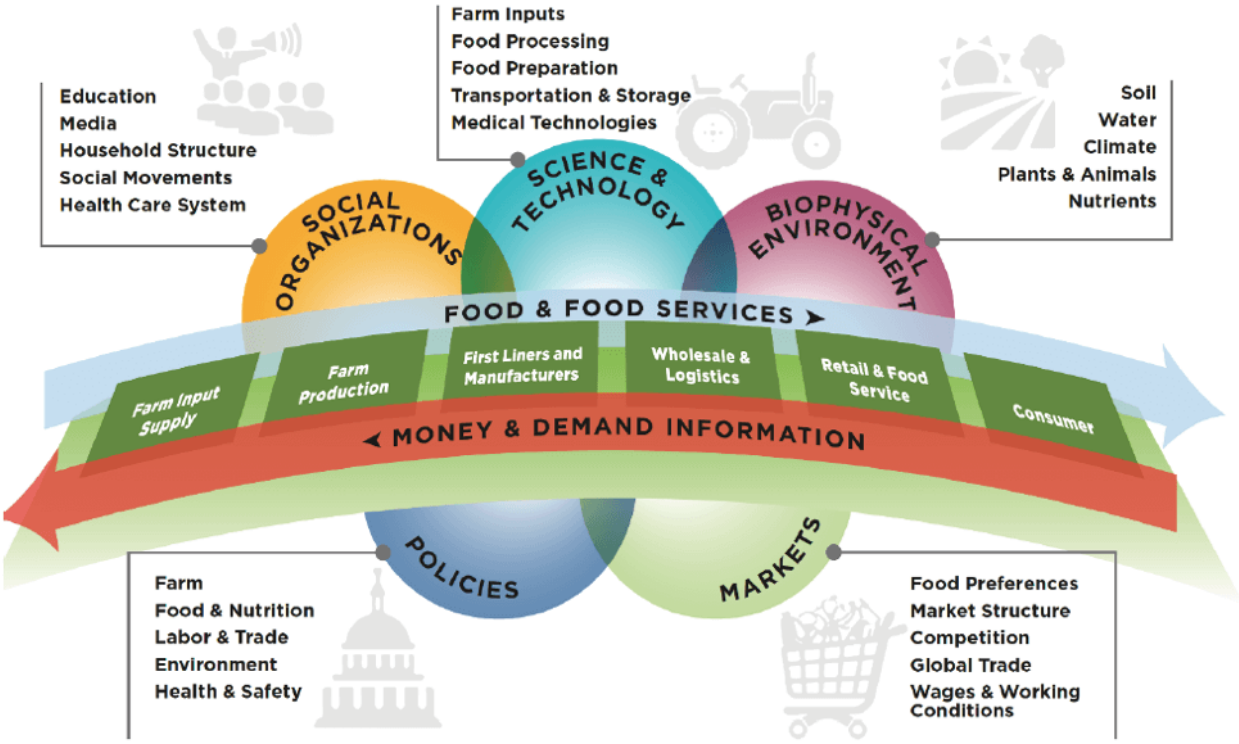
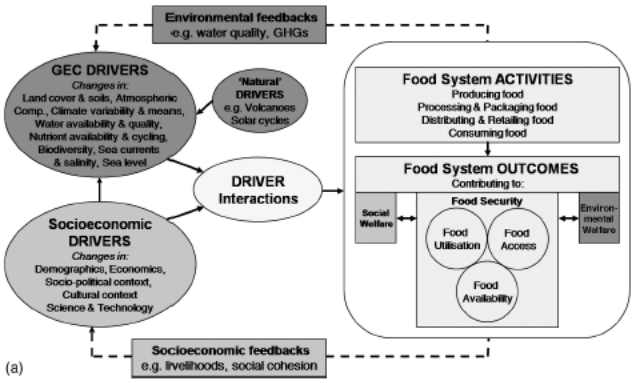


Figure A4: Links between the food supply chain and the larger biophysical and social/institutional context (IOM, 2015: 3)

Appendix 1.2 Diagrams identifying major subsystems and interconnections among them



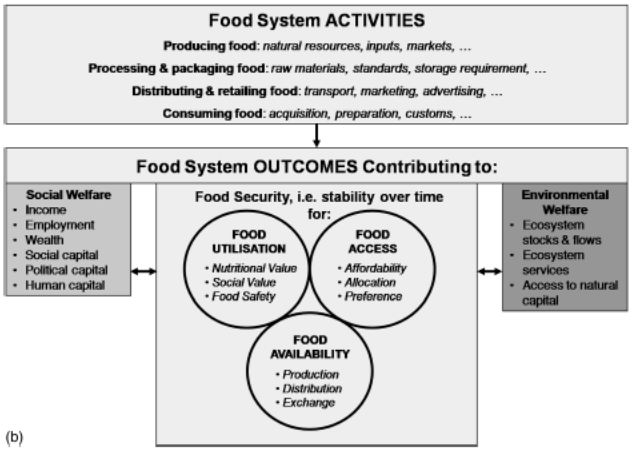


Figure A5: (a) food systems, their drivers and feedback; (b) components of food systems (Ericksen et al., 2010: 28)

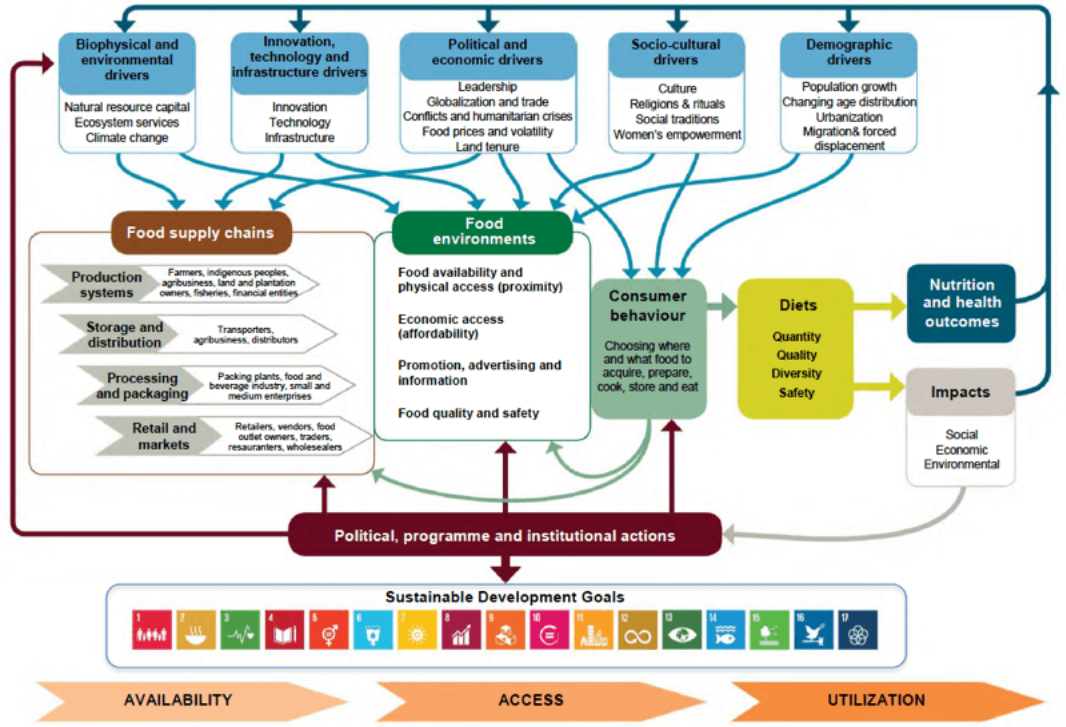


Figure A6: Conceptual framework of food systems for diets and nutrition (HLPE, 2017: 26)

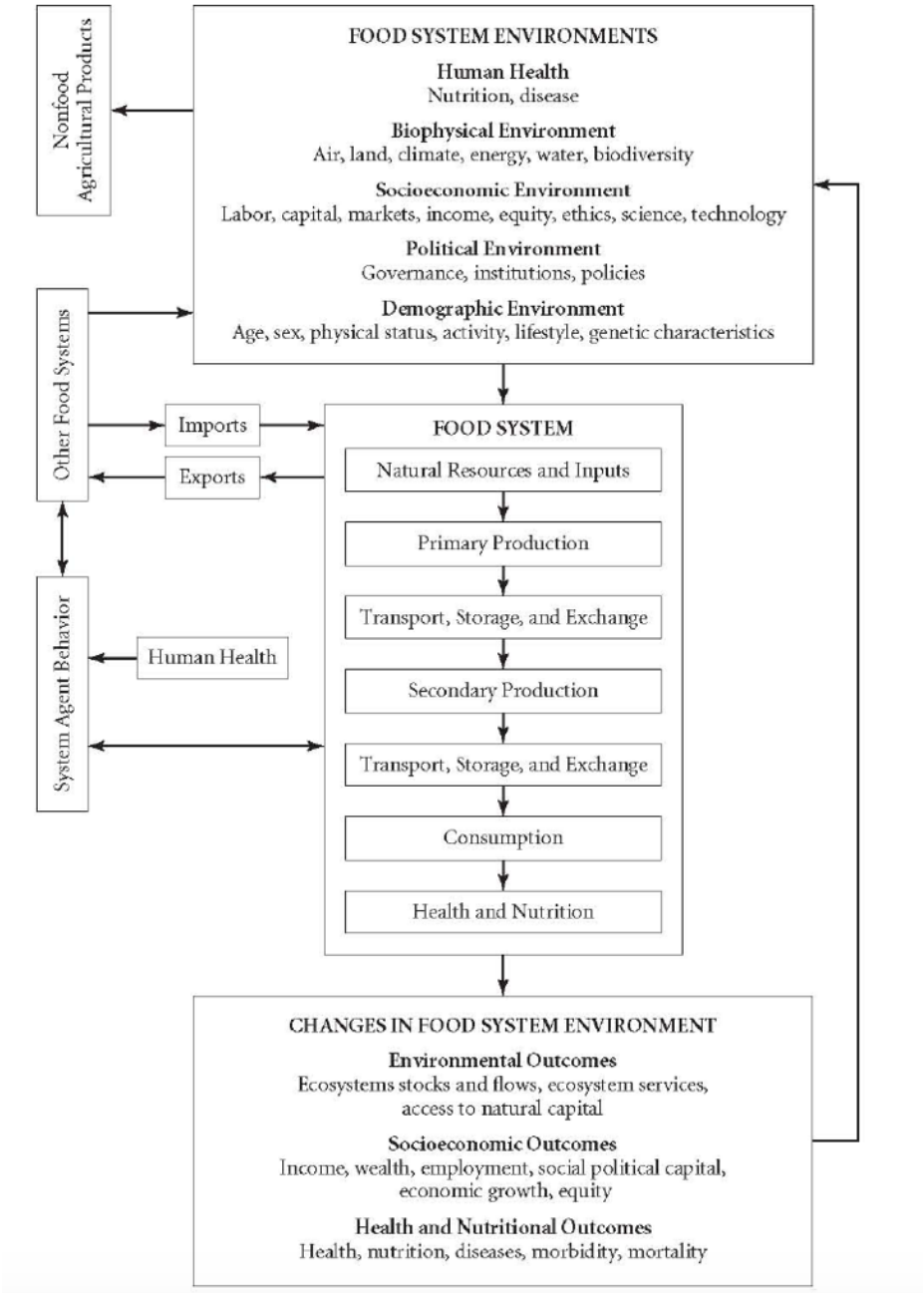


Figure A7: Conceptual framework of food systems (Pinstrup-Andersen & Watson II, 2011)

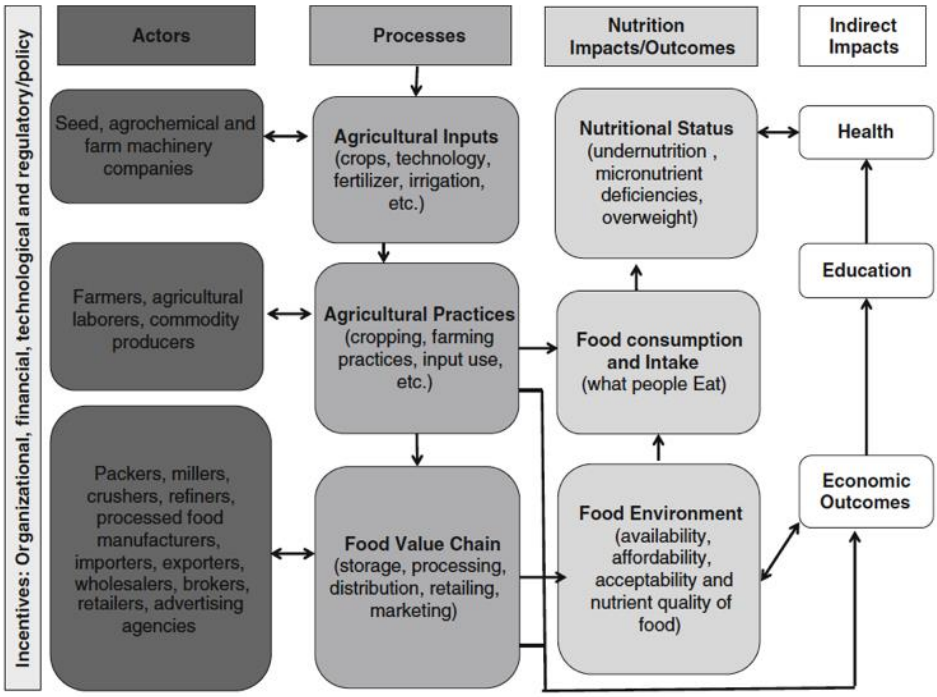


Figure A8: Food value chains for nutrition (Fanzo, et al., 2017: 763)

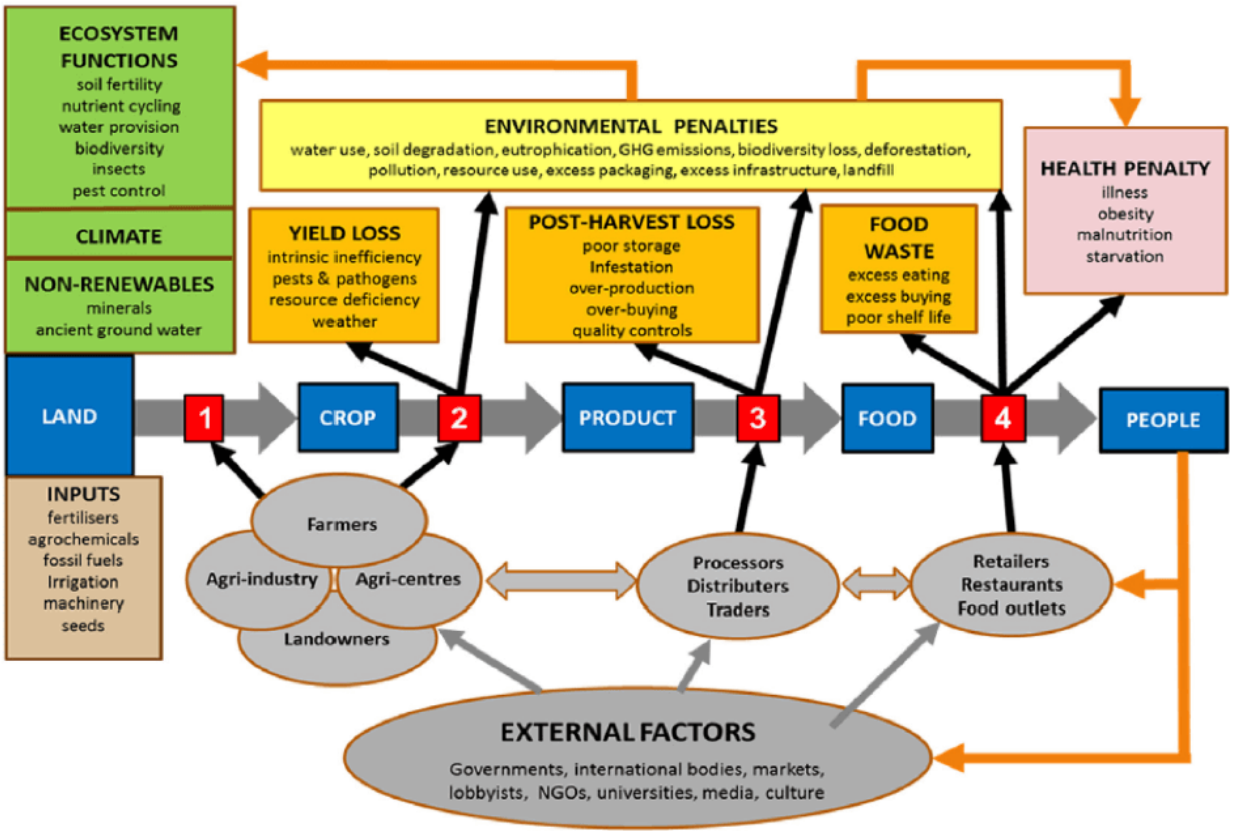


Figure A9: A generic agri-food ecosystem template (Horton, et al., 2016: 166)

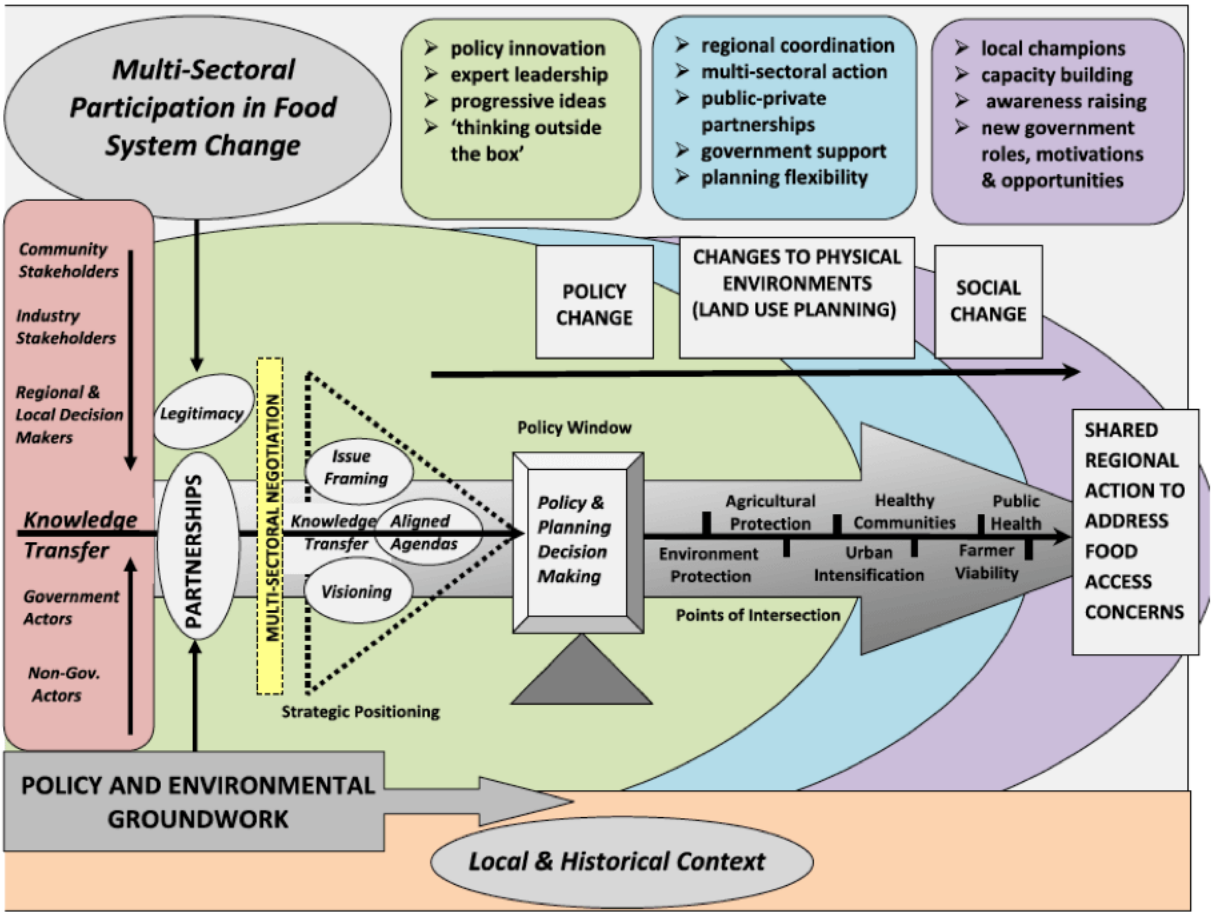


Figure A10: A conceptual framework for multi-sectoral participation and action in food system change (Wegener, et al., 2012: 4118)

Appendix 1.3 Diagrams illustrating pathways between agricultural systems and food and nutrition security

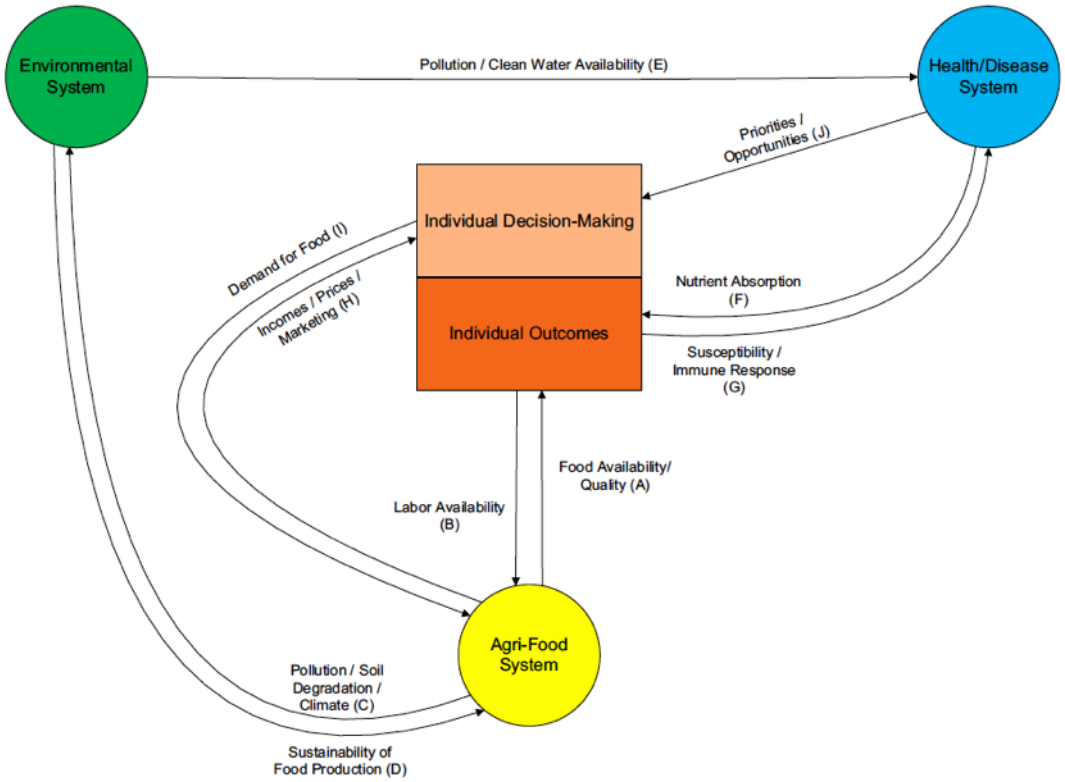


Figure A11: A systems framework for food and nutrition security (Hammond & Dubé, 2012: 12357)

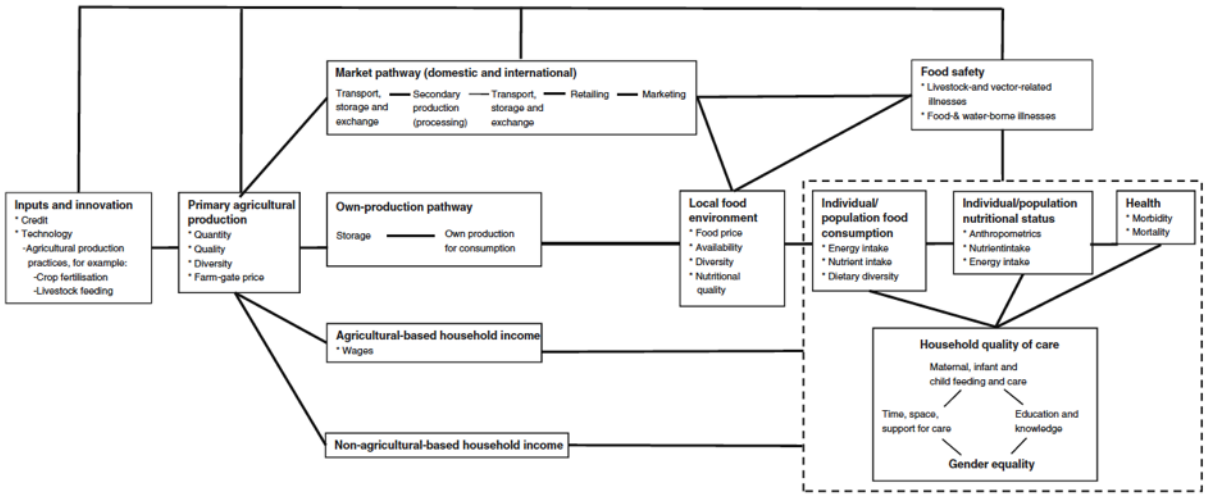


Figure A12: Conceptual framework of the links between agriculture, the food system, nutrition and public health (Kanter, et al., 2015: 771)

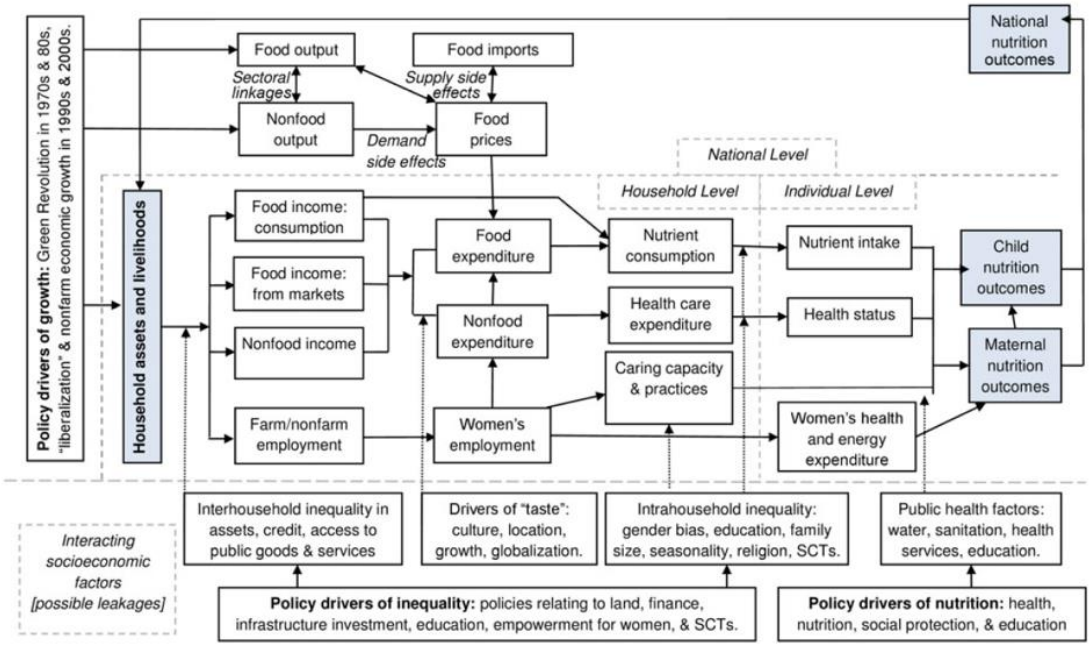


Figure A13: Mapping the agriculture-nutrition pathways in India (Suneetha, et al., 2014: 45)

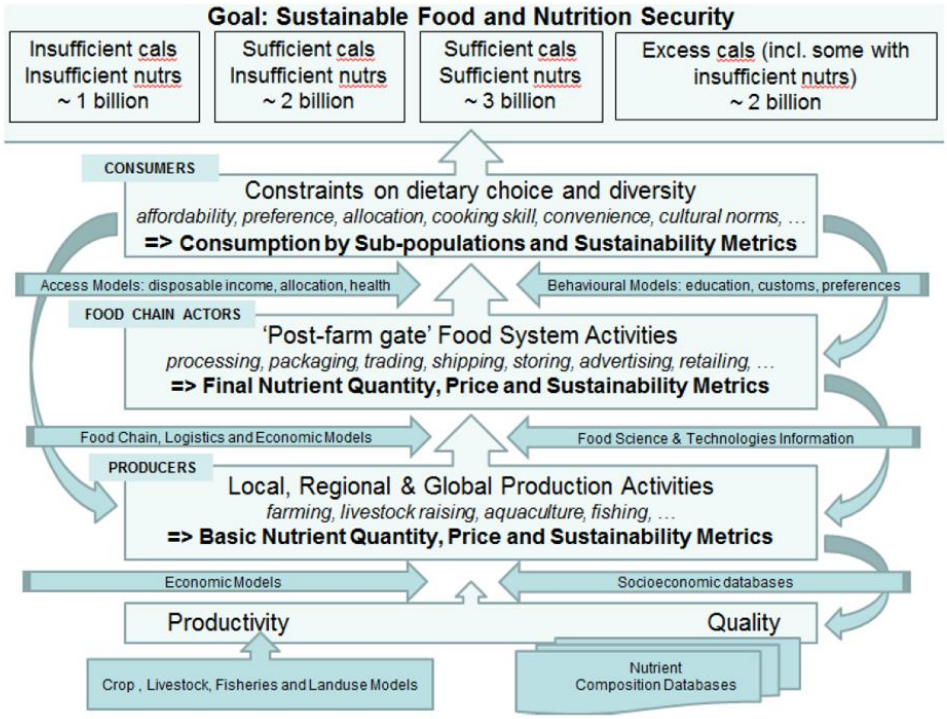


Figure A14: schematic demonstrating the multiple types of information that must be assembled by CIMSANS and partners in order to characterize sustainable nutrition security (Acharya, et al., 2014: 7)

Table A1. Summary of Selected Conceptual Frameworks for Food Systems, Food and Nutrition Security and Overweight/Non-Communicable Diseases, Including Agriculture-Food Security Linkages and Food Security Indicators

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Food System Conceptual Frameworks						
Sobal 1998	Two diagram components. In one, environmental, transportation, economic, cultural, health care and governmental "systems" affect the "food and nutrition system" The food and nutrition system shows the biophysical environment (land, air, water, energy) and the social environment (capital, skills, knowledge) as resources inputs for producers and consumers and "nutrition" and "health". Outputs include wastes, by-products, bio-diversity, policy and institutions, utility, meaning, satisfaction.	Pathways are not clearly shown although perhaps implied by the general flow of the diagram from resource use to production to nutrition.	None	"Nutrition" "Health"	No	Largely a linear depiction of transforming inputs into outputs, and production to nutrition.

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Pinstrup-Andersen & Watson 2001	Food system 'environments' comprise current state of human health, biophysical environment, socioeconomic environment (markets, income, ethics, science, technology), political (governance, policies), and demographic which determine "nonfood agricultural products." The "food system" includes inputs and natural resources, production (primary and secondary), processing, storage, exchange and consumption, which results in "health and nutrition". The food system interacts with "other food systems" via product trade, and "human health" affects behaviors. The food system modifies the "food environment" in terms of biophysical, socio-economic and health and nutrition outcomes.	Only implied by production and consumption leading to "health and nutrition"	None	"Health and Nutrition"	No	Current food systems changes food system environments; a bit awkward in the sense of representing both levels (status) and changes for the food system environment components.

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Randolph et al. 2007	Linkages between livestock ownership and health and nutritional status outcomes, using hybrid causal loop diagram and stock-flow-feedback diagramming approach. Links animals owned to production, labor allocation, land allocation, income generation, consumption (dietary intake), disease exposure and health and nutrition outcomes.	Shows explicit pathways between ownership of livestock and nutrition outcomes, which overlap to some extent with those from Kadiyala et al, but including food, income, expenditure, labor allocation, but also land allocation, dietary change, and disease exposure	None	Growth status (anthropometrics)	Yes, implied	Explicit feedback processes emphasized and hypothesized polarities of linkages indicated, suggesting the potential for offsetting dynamic effects and dynamic complexity.

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Ericksen 2008; Ingram 2011	Global Environmental Change drivers (including 'natural' drivers) and Socio-economic drivers and their interactions affect food system activities (production, packaging, distribution, consumption), which also affect food system outcomes (food availability, access, utilization, social welfare, environmental capital). Feedbacks are shown from food system activities to GEC drivers and from food system outcomes to socioeconomic drivers.	Primary linkage is from food system activities to food system outcomes (including food security) at a high level of aggregation	Food availability, access, utilization mentioned and disaggregated (but more definitions/dimension of them rather than outcomes, i.e., 'affordability' for food access) (aggregated level)	"Nutritional value" under food utilization	No	Some feedbacks between food system activities and GEC drivers, mentions ecosystem stocks and flows. Food system outcomes affect socio-economic drivers. "Used a lot" (and modified by Ingram in 2011, which was used in Stephens et al 2018)
Shift 2009	Food system map with supply and demand, flows of physical inputs and product, money, energy, waste. Conditioning factors include geopolitical relationships, science, technology, socio-cultural, politics and governance, civil security, food security, socio-cultural, geographic, environmental, economic, demographic. Water and energy are key inputs for land, food and consumers, money flows from consumers to farmers, climate change is determined by land use.	Not directly represented. Food security determinants are not clear, shown more as a conditioning factor	"Food Security" shown but not clear how related	None	No	Some linkages but "land" flows through "environment" to" farmers"

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
ShiftN 2009	More detailed global food system map, expanding on many of the elements in the above. More clearly defines some elements, includes other actors in the food system, depicts "availability and options" along with calories and "nutrition" as related to (affecting) consumers.	Production and subsequent processes determine availability, options, calories. Food security still shown as outcome of "civil security" but now defined based on "physical, social, economic access"	Appears in two different locations? "Food Security" derives from "Civil Security" and "Trade and Development Policy", defined as "Physical, social and economic access" (level not clear)	"Nutrition"	No	Many linkages in complex diagram, reasonable capture of many factors affecting food system outcomes
ShiftN 2009	The Food System What's your role? Farming, Social Environmental Economic dimensions, with outcomes determined through the interactions of biological, economic, social and political systems.	Not represented	None	None	No	Linkages but often without feedback, except for those in biological systems, which are primarily influenced by farming practices.

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Hawkes 2009, Hawkes et al. 2012	Actors-Processes-Outcomes-Indirect Impacts framework, with input suppliers, farmers and post-farm processors as actors, processes are: "ag inputs" "ag practices" and "food value chain" and outcomes are "food environment", "food consumption" and "Nutritional Status"	Implies that changes by actors and processes can modify "food environments", food consumption, nutritional status and health	None	Nutritional outcomes include undernutrition, micronutrient deficiencies and overweight	No	Not clear what "economic outcomes" are or why these are influenced by production and food value chain processes. Consumers are not an actor? Education is affected by economic outcomes, and in turn affects "health" which interacts with "nutritional status".
Burchi et al 2011	Food and nutrition security in four boxes for availability, access, utilization and stability, with factors affecting each. Availability is determined by production, trade, processing, storage and distribution. Access is determined by income, markets, intra-HH distribution. Utilization is determined by knowledge, care practices, sanitation and hygiene, and energy use. Stability is related to each of the other three factors.	Implied by factors causing each of the elements of the food security definition	Food availability, access, utilization and stability are mentioned, along with factors affecting them.	None	Yes	Mentions factors that affect stability such as natural disasters, stocks and diversification for "availability". Simple framework without many feedback processes

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Burchi et al 2011	Producer-Consumer-Nutrition subsystems with activities for each; biophysical socio-cultural and policy and institutional environments influence resources and therefore production. An output of the Nutritional subsystem is "health"	Implied by the linkages between the production, consumption and nutrition subsystems.	Consumer subsystem mentions "access"; Nutrition subsystem mentions "digestion and metabolism of food" and "utilization of nutrients"	Nutrition subsystem mentions "digestion and metabolism of food" and "utilization of nutrients"	No	Rather strange that other "environments" don't affect factors other than "resources" and production?

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Gillespie et al 2012	Framework emphasizes the linkages (and disconnect) between agriculture and nutrition outcomes. Household assets and livelihood strategies determine food income (consumption and sales), nonfood income, and employment. Income and employment determine food and non-food expenditures, resulting in nutrient consumption and healthcare expenditures and care capacity (practices). These determine nutrient intakes and health status, which result in child and nutrition health outcomes. At the level of national markets, food and non-food outputs and imports determine food prices, which affect food expenditure. Policy and other drivers affect livelihood strategies, allocation of income, care practices and individual nutrient consumption, health environment, and food prices.	Proposes 7 pathways linking agriculture and nutrition outcomes: 1) Own production - intake - outcome; 2) Ag income - food expenditure - intake - outcome; 3) Food prices - food expenditure - intake - outcome; 4) Ag income - health care expenditure - health status - outcomes; 5) Female employment - food expenditure - food allocation - intake - outcomes; 6) Female employment - caring practices - outcomes; 7) Female employment - female energy - female BMI outcomes.	None	"Child nutritional outcomes", "Maternal nutritional outcomes"	No	Similar to the framework in Kadiyala et al 2014, also indicates that this was "Adapted by the authors from Headey, Chiu, and Kadiyala (2011)." One feedback exists between individual nutritional outcomes, national nutritional outcomes and household livelihoods and assets. Pathways discussed are quite similar to those shown in a different manner in Randolph et al 2007.

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Wegener et al 2012	Factors influencing "shared regional actions to address food access concerns"; focus on knowledge transfer, partnerships, negotiations, policy planning/decision making, points of intersection	Not directly shown, although implies that "action to address food access concerns" will improve food access	"Food access" (not defined)	None	No	Boxes apparently contain factors that contribute to success? Very organizational perspective that is not specific about actions or outcomes.
Ecker and Breisinger 2012	Emphasizes macroeconomic impacts, which affect "subsistence" "income" and "public services". Micro (Household) level includes primarily the access component, with categories for "food" and "Assets and Services". These are affected by resources, but in turn affect intake and health, which determines "nutritional status". There are linkages from NS to human capacity and productivity, which in turn affect economic and social development...which feeds back to micro level (but not macro level) variables. Interventions or external shocks affect the entire structure.	Food access (through income, prices, own-consumption) determines food and nutrient intake, which determines nutritional status and health status. Access to assets and services also affects food access (not entirely clear by which pathways).	None explicit	"Nutritional status"	Not explicit	For a diagram that is supposed to represent an new conceptual approach to food security, it is rather curious that it does not explicitly show this.

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Kadiyala et al 2014	Focus on policy drivers and how they affect economic growth, inter-household inequality, "tastes", intra-household inequality, and public health. Delineates the national, household and individual levels. Household assets and livelihood strategies determine income from direct production and from markets, nonfood income and employment of household members. This determines food and non-food expenditures, which determine nutrient consumption, health care consumption, and care practices. These determine nutrient intake at the individual level, as well as health status and women's energy status. These determine "nutrition outcomes" for children and women, which can be aggregated for national outcomes. This influences household assets and livelihood strategies.	Delineates 6 pathways: 1) agriculture as a source of food, 2) agriculture as a source of income for food and non-food, 3) supply and demand influence food prices, 4) women's decision making about agriculture and resource allocation, 5) maternal employment and care practices, 6) women in agriculture and nutrition and health status. (These are more clearly discussed as pathways in the Gillespie et al 2012 paper upon which this is based.)	None	Nutrient intake, health status, child and maternal nutrition outcomes (individual and national levels)	No	National outcomes affect household assets and livelihoods, otherwise a linear flow of causality implied.

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Global Panel on Agriculture and Food Systems for Nutrition 2014	Focus on how agricultural and food system policies link to dietary quality. The "Food Environment" encompasses "diet quality" (diversity, adequacy, safety). The FE is determined by four factors "Market and Trade Systems" that facilitate the exchange and movement of food, by "Agricultural Production" (own consumption and sale), "Consumer Purchasing Power" (income from farm and non-farm sources), "Food Transformation and Consumer Demand" (food processing, retailing, and demand). Policy options for each of these four are presented.	Indicates that the food environment determines diversity, adequacy and safety. Agricultural production influences this, as does food trade, post-production processing and distribution, and income.	Only implied through diversity and adequacy of diet quality	None	No	Emphasizes food environment and policies from different areas that could affect it. Does not elucidate pathways or explore interactions.
Lawrence et al 2015	"Environment" influences (and is influenced by) the "Food System" (production, packaging, distribution, consumption) which leads to Public Health Nutrition outcomes. Considers resource supply and demand as well as food supply and demand. Consumption is shown affecting all other elements of the food system. Public health nutrition is shown having a smaller impact on the food system.	Only implied by production and consumption leading to "public health nutrition"	None	"Public Health Nutrition"	No	Some feedback processes include the food system affecting the environment, consumption affecting the previous stages of the food system, and public health nutrition affecting the food system.

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
IOM and NRC 2015	Food system from farm input supply to consumption (as in a supply chain) flows of physical product and related service, money and information, affected by social organizations, science and technology, biophysical environment, policies and markets.	Not directly represented	None	None	No	Linear from inputs to consumption
IOM and NRC 2015	Framework for analysis of food system issues, from problem definition to reporting	Not directly represented	None	None	Not explicit	More a representation the process of analysis than a conceptual framework linking to food security and nutrition outcomes. Does recommend: "Account for system dynamics and complexities" "feedbacks and adaptation"
IOM and NRC 2015	Figure 6.1 Food system as a dynamic process transforming the state of natural resources and human systems from one period to the next. Ag inputs, production, post-farm and consumption transform human system outcomes (health, markets, policy, well-being) and natural resources (air, biota, land, water) over time	Only implied by how the food system determines states of human systems (including "health")	None	None	Yes	Focus is on the dynamics, but very high-level diagram

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Tendall et al 2015	Food system resilience and action cycle (Shock, absorb, react, restore, learn, build robustness) reaction, prevention, in response to stressors	Not represented	None	None	Yes	Explicit feedback process for resilience, but very general
Arachya et al 2015	Focus on information flows and needs (including models) for "Sustainable Nutrition Security"; production, post-farm activities, constraints on dietary choice and diversity. General flow is from productivity/quality to poduction, post-farm gate, then consumption (in the face of constraints). These lead to acheivement of goals, but these are specified in terms of what seem to be current values for numbers of people in different categories. There are linkages from consumers to producers, from consumers to post-farm activities, and from post-farm to farmers.	Not directly represented. Consumption and constraints on choice affect Sustainable Nutrition Security. Consumption depends on post-farm activities and production activities.	"Sustainable Nutrition Security" (4 categories based on calories and 'nutrients', suffiicent or excess), global?	Same as Food security indcators	No	Focuses on information needs and the use of models, but very general and rather inconsistent (combines 'production' with 'constraints on dietary choice and diversity'
IFPRI 2016	Depicts enabling, underlying and immediate processes that result in "nutritional status" and "development outcomes." Key underlying processes include factors related to food environment (affordability and access), social (norms on child care, working conditions), health (access to medical services), living environments (built space, water, sanitation).	Not directly represented. Does include "food environment", "food systems" and "agricultural development" as elements.	None	"Nutritional status" means, underweight, overweight, obesity, high blood pressure, high blood sugar, high cholesterol	No	Interactions among elements, but generally linear, not feedback. Ultimate outcomes include NCD, mortality, cognitive, labor productivity, pregnancy outcomes

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Horton et al 2016	Generally linear flow of Land-Crop-Product-Food-People, environmental focus, emphasis on negative outcomes. Shows inputs (including ecosystem functions, climate and non-renewable resources), as well as the actors/decision makers and external factors (largely other actors, such as 'government' and 'media') at each stage. Outcomes are shown as negatives (yield loss, post-harvest loss, food waste, 'health penalty' (illness, obesity, malnutrition, starvation) and 'environmental penalty'. The latter has a negative effect on non-purchased inputs. "People" have an impact on the decisions of the food system actors and the "external factors".	Only implied by the linkages between crop-product-food-people and negative outcomes under 'health penalty'	None	"Health penalty" (illness, obesity, malnutrition, starvation)	No	Feedback processes to "ecosystems functions" through "environmental penalties".
Fanzo et al 2017	Nutrition focused food value chain framework based on Michael Porter; Support activities include infrastructure, HR management, technology development, procurement. Primary activities include inbound logistics, operations, outbound logistics, marketing and sales, service	Implied by the overall outcome "added value for nutrition" and suggests that various processes and interventions may be beneficial	None	None	No	Seems like a rather strange adaptation, with "added value for nutrition" as the equivalent of margin without a clear delineation of market versus programmatic efforts.

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Allen and Prosperi 2016	Causal pathway diagram, showing linkages among a specified driver, other drivers, potential impact, resilience and vulnerability.	Not directly represented	None	None	Yes, implied	More a framework to understand basic concepts in resilience and its analysis. Includes explicit feedback linkages
Allen and Prosperi 2016	Basic representation of a dynamic system, including external variables, control variables, state variables, and output variables, with feedback shown and with system boundary.	Not directly represented	None	None	Yes, implied	More a framework to understand basic concepts in dynamic systems, but includes explicit feedback linkages.
Allen and Prosperi 2016	Sustainable food system framework, adapted from Ericksen and ingram. It combines the GEC and socio-economic drivers, omits natural drivers and does not explicitly represent the interactions as in previous versions. Its contribution is to explicitly incorporate the causal pathway and dynamic systems components into the diagrams noted above.	Food system outcomes (including food security) result from vulnerability/ resilience (rather than from food system activities as in previous versions) still at a high level of aggregation	"Food and Nutrition Security"	None	Yes, implied	Shows environmental and socio-economic feedback processes

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Herforth and Ballard 2016 (cited in FAO 2016)	Categorizes pathways into outcomes and impacts. Outcomes include farm production, food environment, Income, women's empowerment, nutrition knowledge and norms, natural resource management practices. These determine impacts: food access, care practices, health/sanitation environment, which affect "diet" and "health", which determines "nutritional status". Interventions affect "outcomes"	On-farm availability, the food environment, and income determine food access, diet and nutritional status. Income, women's empowerment and knowledge determine care practices, which affect diet and health, natural resources management determines health and sanitation environment.	Not a focus, only access is mentioned	"Nutritional status"	No	Not sure if food access is considered a subset of availability and stability, but it appears so.
FAO 2016	Resilience framework shows changes in income (Y?) and resources over time. Access to "basic services", assets, social safety nets and adaptive capacity mediate the response of households to shocks, which consist of consumption smoothing, asset smoothing and new livelihood adoption, which in turn determine future Access, assets, safety nets and adaptive capacity. Other "household time-invariant characteristics" are shown.	None explicit	None	None	Yes	The framework focuses on the intertemporal dynamics, hypothesizing that response strategies to shocks are determined by initial assets. Does not really account for feedback processes or time delays.

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
HLPE 2017 (2 versions)	First diagram shows a sequence of food supply chains determining food environment, personal filters, consumer behavior determining "diets", "nutrition and health outcomes" and "other (social, economic, environmental) impacts". Multiple external drivers (e.g., climate change, globalization, urbanizations) are shown affecting entire set of relationships. Second diagram more clearly delineates the food supply chain actors, and divides the drivers into biophysical/environmental, innovation/technology/infrastructure, political/economic, socio-cultural, and demographic categories, with clearer linkages with other components of the diagram, and links them to outcomes.	"Food production" is one element of food supply chains, but this tends to suggest other than self-supply and the linkages between agriculture and nutrition are not direct.	None	"Nutrition and health outcomes" (level not clear)	No	In second diagram, drivers are made endogenous, perhaps suggesting dynamics. Consumer behavior affects food environment and food supply chain, and "other impacts" affect food supply chains through political, program and institutional actions, as well as through the drivers.

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Dobbie and Balbi 2017	Food availability, access, stability and utilization in diagram, with causal factors for each. Availability based on own production and other sources of food. Access is determined by availability, stability and "spending capacity". Stability determined by those of markets, political and production (climate-related). Utilization determined by access and ability to process, as well as "potential dietary intake".	Shows (selected, generally household-level) pathways from domestic production and other sources through all elements of the food security definition, including availability, access, utilization and stability.	Four components of the basic food security definition, but no specific indicators.	None	Not explicit	Rather linear framework that represents the logic for an ABM model that is explicitly dynamic and rather feedback rich. Quantitative analysis includes proportion of "food energy deficient" households and proportion of energy from staples.

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Garrett 2017	Community, household and individual levels. Market availability, environmental services and health services affect access, cost and health status. Household production and transfers, income and prices affect availability, access and household hygiene. HH care and feeding behaviors affect nutrient intake, which along with health status affects nutritional status	Market availability, home production and income and prices determine access to food and availability, which affects food and nutrient intake. Environmental and health services affect hygiene and health status, which combines with intake to determine child nutritional status.	Food/Nutrient Intake	Child nutritional status	No	Most frameworks begin with availability (perhaps more appropriate for aggregate) whereas this one as access first. Recognizes the role of transfers and market access in addition to own production.

Framework	Key Elements	Agriculture-Food Security/Nutrition Linkages	Food Security indicators Included	Nutrition indicators Included	Is Dynamic/ Stability Explicit?	Comments
Hammond et al 2017	Farm types, farm practices, "performance indicators" (as indicators of the three pillars of CSA). Practices include "intensification", "diversification" and "market orientation". These lead to "food availability", "farm productivity", "Dietary Diversity" and "food insecurity of access", which lead to "food security"	Actions such as diversification, intensification and market orientation determine food availability, dietary diversity, farm productivity, food access insecurity. These actions are conditioned on farm size and ownership of livestock. Pathways not entirely clear.	"Food security" determined by (only) farm practices, through availability, dietary diversity	None	No	Mostly a structure to show the data collection logic for RHoMIS related to CSA. "Practices" seem more appropriately termed "strategies". Productivity lumped with (conflated with) food availability, not clear what "food insecurity of access" means.

Food Security-focused Frameworks						
UNICEF 1990 (also cited in UNICEF 1998)	Causality model of malnutrition, includes Basic, Underlying and Immediate causes of "malnutrition". Potential resources are transformed into "Resources and Control" through political, ideological and economic factors/structure. Resources cause "inadequate education", inadequate food access, inadequate care, insufficient health resources and unhealthy environment. These determine inadequate dietary intake and disease, which together cause malnutrition. Shows interactions between malnutrition and poor care, disease and intake.	Control of resources affects food access, care for women and children, and health environment. These in turn affect dietary intake and disease status, which together determine "malnutrition".	Mentions "food access" as inadequate	"Malnutrition"	No	Could benefit from the use of consistent polarity (i.e., "resources" should not result in "inadequate education"). Some linkages, but no feedback or implied dynamics or responses to shocks.
UNICEF framework (as adapted by Sassi, 2018)	Conceptual framework for child undernutrition that delineates Basic, Underlying and Immediate causes. Basic causes include the sociocultural, economic and political context, inadequate (HH-level?) forms of capital, and household access to resources. Underlying causes include "household food insecurity", inadequate care and feeding practices, and unhealthy environment including lack of health services. Immediate causes are low intake and disease. Short and long-term consequences are shown, with long-term linking to basic and underlying causes.	Household access to adequate resources (land, education, employment, income, technology) determines "food insecurity", care practices, and health environment. These in turn affect dietary intake and health status, which determine child undernutrition.	None	"Child undernutrition"	Implied, through linkages back to Basic and Underlying Causes	Not focused on food security per se.

Rutten et al 2011	Conceptual of food systems and food security that shows a linear model of subsystems from Environmental Resource Inputs to Producer to Consumer to Nutrition to Health Outcomes. Producer (really, production) includes production, processing and distribution. Consumer includes acquisition, preparation and consumption. Nutrition includes digestion, transport and metabolism. Also shows a set of "barriers" that suggest a linkage between which "subsystem" fails and the degree of food insecurity.	Environmental resource inputs determine production, processing distribution, which determines acquisition, preparation and consumption, which determines digestion, transport and metabolism. Together, these determine "health outcomes"	Not explicitly mentioned	None	No	Very linear model. "Health outcomes" are not delineated. Actors not delineated.
Hammond and Dube 2012	Systems framework for food and nutrition security that shows the Agri-food system, Environmental system and Health/Disease system interacting and influencing individual decisions which in turn affect individual outcomes. Individual decisions influence "demand for food" which in turn affects "incomes, prices and marketing". Health and disease system affects "nutrient absorption", which in turn affects health through "immune response". Pollution and water quality from the environmental system affect health status. Pollution and sustainability of food production affect the Agri-food system.	Not explicit, although the Agri-food system affects individual outcomes through "food availability / quality". Nutrient absorption is affected by the Health/Disease system.	Not explicitly mentioned, although "food availability/quality" is an element that affects individual outcomes	"Nutrient absorption" shown as a process that affects individual outcomes	Implied, through feedback loops shown.	High level diagram that emphasizes a limited number of interactions among the three systems. The decisions and outcomes for individuals are not clearly specified, nor are social factors or the "food environment" accounted for.

FAO 2000	FAO developed the FIVIMS framework that depicts the National/Subnational/Community, Household and Individual Levels. First of these includes the "vulnerability context" derived from socio-cultural, political, institutional, cultural and natural environment (includes factors like policies, climate, markets, etc.) Also in the first level is the "Food Economy", which includes (aggregate) food availability, stability and access to food. Households include livelihood strategies, HH-level food access, care practices, health and sanitation. Food access and care practices determine food consumption. Food consumption interacts with health and sanitation to determine food utilization, which in turn determines nutritional status	A variety of factors that make up the "vulnerability context" affect the national "food economy" (availability, stability and access to food). Household food access is determine by livelihood assets and strategies, food availability, stability and income. Household food access affects care practices and food consumption, care practices also affect consumption. Health and sanitation affect food utilization, which together with consumption determines nutritional status.	Includes availability, access (two levels), and utilization components	"Nutritional status"	No	Latest version from 2013 FAO eLearning course on food security presentation. Very linear diagram, but does contain all of the basic elements of food security

Kanter et al 2015	Shows linkages between agriculture, the food system, nutrition and public health. Linear linkages from inputs to ag production, which provide inputs for post-farm "market pathway", "own production" pathway, household farm income and non-farm income. Production mediated by post-farm determined the local food environment (price, diversity, nutritional quality), with food safety linked to production and processing. Food environment and income determine consumption, which appears to cause nutritional status, and "health" all of which are influenced by "HH quality of care"	Identifies own-production and market pathways, which influence the local "food environment" (price, availability, diversity and quality). This and income influences food consumption (intake) which along with "Health" and quality of care, determine nutritional status.	Not explicitly mentioned, but includes intake and dietary diversity in "consumption"	Energy and "nutrient" Intake and "anthropometrics"	No	Agriculture is not part of "the food system"? Not clear how farm production causes non-farm income? Acknowledges some factors/linkages omitted. Seems more appropriate for a higher-income country? I don't find the diagramming linkages particularly clear.

de la Peña et al. 2018	Focus is on how the development of Nutrition-Sensitive Value Chains (NSVC) can improve diets and nutrition outcomes. Essentially, NSVC means promotion of products deemed to meet nutritional shortfalls in a given context (examples provided include dairy, beans/legumes, fruits and vegetables and bio-fortified crops). Promotion implies some combination of increasing production, increasing demand and "adding nutritional value". Actions in the value chain to increase supply include more production, improved post-harvest practice, market access and VC coordination. Actions to increase demand are focused on improved nutrition awareness. Actions to "add nutritional value" are less clear but appear to be those that would modify available nutrients (e.g., crop selection) reduce physical and nutrient loss and improve food safety. Together, these modify the "food environment" modify diets, care practices and therefore nutritional status.	Three pathways are delineated: 1) increased supplies increase income (full or cash), 2) own production results in greater availability of (nutrient rich) foods and 3) greater market availability makes (nutrient rich) foods less expensive and available for a larger number of households. Each of these changes, particularly when combined with efforts to improve nutrition awareness, is expected to change consumption patterns, improve diets, and improve nutritional status.	None	"Nutritional Status"	No	Pathways are similar to those identified in Gillespie et al 2012 and Kadiyala et al 2014. Activities really appear to be general categories of objectives (increase demand, increase supply, add nutrition value). Linear framework that does not assume feedback effects.

Rutten et al 2018	Conceptual framework for sustainable EU food and nutrition security that shows producers, food chain actors, and consumers, all of which are affected by the "socio-economic" environment. Producers respond to "business" incentives to produce, which results in availability of food and nutrients ingredients, prices, and sustainability metrics. Food chain actors respond to business incentives to process and distribute specific food products, which determines final (consumer-ready) availability of food and nutrients, prices and sustainability outcomes. Consumers make decisions on the basis of "access" (availability and prices) and underlying behaviors and preferences, which result in diet choices and sustainability metrics and which generate FNS. Includes "goals" of competitive agri-food businesses, "balanced diets", reduced environment impact, and contributions to global FNS.	Production level determines basic food and nutrient availability and price. Subsequent food chain actors determine final food and nutrient availability and price. Consumers diet choices determine food and nutrition security by population segments.	"Food and nutrition security"	None	No	Modification of the diagram from Arachya et al 2015. Shows linkages as dual-directional arrows between elements. Not clear how the goals affect the (overall box) that shows the "EU agri-food-nutrition system"

Sassi 2018	Food security conceptual framework that links the "Food Economy" with the "Household Context". Food economy includes markets (aggregate availability) with prices. Household production is determined by assets and coping strategies, which along with transfers determines income and thus food access. Food access determines intra-HH allocation, which appears to determine intake, health status and care behaviors, which determine "individual food and nutritional status"	Household assets and coping strategies determine production of food and cash crops, and other activities. These in part determine incomes, which along with market availability determine prices and food access. Food accessed is allocated in the household to determine intake, and health status and care behaviors determine food and nutrition status.	Food availability and access mentioned, utilization implied. Stability shown as dashed-line box not connected to anything.	"Food and nutrition status"	No	Very linear framework with no feedback mechanisms, stability mentioned but not really integrated.
Wossen et al 2018	Framework linking climate and price variability to adaptation options and food security. Climate variability influences yields and price variability, and the latter also influences (future) yields. Yield impacts affect adaptation, which is affected by markets, institutions and assets. Adaptation affects yields. Adaptation results directly in Food Security	Markets, institutions and assets determine "adaptation" which determines food security. No pathways.	"Food Security"	None	Only implied by "variability"	High-level diagram that shows only very general relationships, that underlying the specification of the model and scenarios.

DFID, undated	Sustainable livelihoods framework links human, social, natural, financial and physical capital. Livelihood assets determine "vulnerability context", which is also affected by Policies, Institutions and Processes. Together, these determine Livelihood Strategies, which determine Livelihood Outcomes (income, well-being, vulnerability, "food security", sustainable use of natural resources	Livelihood assets interact with policies, institutions and processes to determine livelihood strategies, which result in food security.	"Food security"	None	Not explicit, implied by linkages between Livelihood Outcomes and Livelihood Assets	This diagram is not particularly clear compared to perhaps others that represent these concepts. Dynamics are implied by words like "more", "reduced", "improved" describing livelihood outcomes. What is a "process"?

WFP (2012)	Conceptual framework of Food and Nutrition Security that builds on the sustainable livelihoods framework. Shows components at the Community/HH level, the HH level and the individual level. The context/framework shows "food availability /markets", basic services, infrastructure, political, economic, social, institutional, security, cultural, gender and environment, climate as factors affecting all levels. Assets (capital of five types) affects livelihood strategies such as production, gifts, exchanges, cash, loans, savings, transfers, as well as care/health practices. Livelihood outcomes (food access, care/health practices, health and hygiene conditions) are affected by assets and by strategies. These determine food intake and health/disease status, which in turn determine nutrition status and mortality.	Assets/Capital determine household's ability to produce or acquire food or other resources. This determines food access, care practices, and basic health conditions, which determine intake and health status, which determines nutrition status/mortality.	Food availability is exogenous at all levels, food access is shown at the household level	"Nutrition Status" and mortality		Appears to be a combination of the DFID and UNICEF frameworks Shows linkages from nutrition status back to livelihood assets strategies and outcomes
Frameworks More Related to Overweight and Nutrition-Related Non-Communicable Diseases (NCD)						
Story et al 2008	Factors affecting some unspecified outcome, including the macro environment, physical environment, social environment and individual factors. Boxes contain factors comprising each of the 'environments' as well as mechanisms or factors that could modify their impacts	None explicit	None	None	No	Similar to Herforth and Ahmed but with different categories.

Malik et al 2012	Factors affecting obesity, driven by globalization, economic growth and urbanization, which include changes to the built environment, changes to physical activity levels and changes to stress and sleep patterns.	Pathways from 'globalization' to obesity are outlined but seems rather incomplete and overly simplistic	None	Obesity	No	As shown, diagram says that the ultimate cause of obesity is globalization, along with economic growth and urbanization. Some linkages seem possible, but overly simplistic
Klatt 2014	Diagrams factors affecting food intake and thus energy imbalance. Includes 'external' and 'internal' influences	Only "cost of commodity prices" appears linked to agriculture	None	Energy balance or imbalance	No	From a blog about “fed up with obesity.” More a hierarchical listing of suggested causal factors, without indicating a direction of causality

Anand et al. 2015	Food systems and Non-communicable disease linkages. Food system drivers, food system, price/availability, nutrition consumption factors, nutrition outcomes, health outcomes	Price and availability are determined by the "food system", which in turn affects quantity, quality and diversity of consumption. This then affects nutrition and health outcomes.	None	"Balanced diet", under/over-nutrition, nutrient deficiencies	No	"Food system" = value chain actors? Linkages
Herforth and Ahmed 2015	Food environment factors determining intake and physical activity, including social and cultural norms/values, 'sectors of influence', environmental settings, and individual factors	None explicit. (Agriculture is listed as one of the "sectors of influence" but does not appear meant in any biophysical sense.)	None	None	No	Sectors of influence include government, marketing, etc., Environmental settings are places were food is consumed.

Mozaffarian 2016	Food environment variables at that global, governmental, industry, community, socio-cultural, and individual levels, shown as nested--these are all determinants, with the implied outcome being "healthy eating"	Not explicit, although the factors could influence choices and thus outcomes.	"Global food availability" is listed as a determining factor	None	No	This is just a listing of causal factors without outcomes other than "healthy eating." Nesting of factors seems correlated to some notion of 'scale', but a bit strange (government is bigger than industry? Socio-cultural is different than community?)

Table A2. Summary of N=84 Papers Resulting from Scopus Search of Terms "Household Food Security Models" for which the Abstract Suggested an Empirical Model with Clear Linkages to Food Security Outcomes Other than Yields or Production

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Leonardo et al. 2018	Small-holder maize farmers SSA	Simultaneous equations optimization model with multiple objective functions, constraints	Agricultural household model used to connect consumption/production sides for small-holders, evaluate tradeoffs in policy objectives	Maize self-sufficiency (HH FS objective), maize sales (national policy objective)
Islam et al 2018	Farm diversification and food security, Bangladesh	Statistical model with panel data	Estimate of impact of farm diversification on multiple FS indicators	HDDS, WDDS, FVS
Ragasa and Mazunda 2018	Farm input subsidies vs food security, Malawi	Statistical model with panel data (correlated random effects)	Estimate impact of FISP on food security, uses agricultural household model to embed decision-making hierarchy	HDDS, FVS, FCS
Radchenko and Corral 2018	Agricultural commercialization vs food security, Malawi	Statistical model	Estimates commercialization factors on FS, agricultural household model as framework	Food expenditure, FCS
N'Danikou et al 2017	Foraging and FS, Mali	Statistical model	Looks at rural-to-urban continuum of households, focus on agrobiodiversity	Self assessment, coping strategy index
Whitney et al 2017	Homegardens and FS, Uganda	Simulation model	Assesses impact of gov. policy supporting homegardens vs. FS, quality of food as model output	Nutrient content of specific foods vs. Dietary Reference intake
Wineman and Crawford 2017	Climate change and crop choice, Zambia	Mathematical programming model	Linear programming mostly focused on yields, but also calorie consumption	Calories as % of threshold

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Inder et al 2017	Livelihood strategy choices and child welfare, Zambia	Statistical model, AHM	Estimates differential impact of different livelihood strategies on calories consumed across demographic groups	Calories as % of threshold
Habyarimana and Nkunzimana 2017	Land use consolidation policy and livelihoods, Rwanda	Statistical model/regression	Compares policy adopters vs. non adopters and different outcomes including FS	FCS
Darsono 2017	Staple food self sufficiency (rice), Indonesia	Statistical model/regression	Looking at correlates of rice self-sufficiency	Rice self-sufficiency
Djebou et al 2017	Comparative study of subjective FS across several SSA countries	Statistical model/regression	Looks at correlates of FS	Subjective FS self-assessment
Nkegbe et al 2017	Assesses impact of 'Feed the future' program, ag system, Ghana	Statistical model	Tests if FTF is significant in raising FS	HH Hunger Scale
Dil Farzana et al 2017	Large sample analysis of various coping strategies and FS, Bangladesh	Statistical model	Has ag data as exogenous variables, rather than ag systems, but 23,000 observations on many strategies used	HFIAS
Akerele et al 2017	Rural nutrition determinants, Nigeria	Statistical model	Ag system variables as exogenous influencers of nutrition, diet	Food consumption diversity
Zereyesus et al 2017	Off-farm labor and food security	Dynamic statistical model (FGLS)	Looking at food poverty and vulnerability, AHM embedded in decision-making framework	Expected future food consumption, predicted shortfall from food poverty line
Rigolot et al 2017	Climate policies in mixed crop-livestock systems, Burkina Faso	Simulation model (dynamic AHM, IAT?)	Looking at policy intervention impacts/trade-offs	Food security ratio (Rufino 2013), calories as % of threshold
Hammond et al 2017	Climate smart ag in E. Africa, C. America	RHoMIS survey instrument	Survey designed to quickly assess impact of climate smart ag., suitability, gender equity indicator, poverty transitions	HDDS, HFIAS, calories as % of threshold

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Traore et al 2017	Cereal crops and climate risk, Mali	Statistical model	Mostly ag production model, with normative assessment wrt food self sufficiency	Food self-sufficiency
Hussien et al 2017	Water-energy-food interactions, Iraq	System dynamics	No agriculture currently but easy to imagine adding it in	Food consumption
Beghin and Teshome 2017	Coffee/cash crops and food security, Ethiopia	Statistical model	Ag system as explanatory factor in food security attainment	Self-reported food shortages
Akerele and Shittu 2017	Food production and diet diversity, Ethiopia	Statistical model	Ag variables as explanation for diet	Diet diversity
Joshi and Joshi 2017	FS in mountain regions, Nepal	Statistical model	Comprehensive national survey, ag vars as determinants of FS	FIVIMS (FAO, 2001)
Ali and Erenstein 2017	Climate change adaptation and FS for farmers, Pakistan	Statistical model	Basic ag econ study relating farm variables and demographics to FS outcomes	Calories as % of benchmark
Hadush 2017	Animal feed and water scarcity impact on consumption, Ethiopia	Statistical model	AHM used to frame statistical estimates of determinants of consumption	Yields, per capita food consumption expenditures
Wane et al 2017	Dairy supply chain and food security, Senegal	Statistical model	Porter value chain applied to milk, and implications on food security, focus on gender	HFIAS
Ogot et al 2017	Farm technology adoption and children's nutrition, Kenya	Statistical model	Basic ag econ model with FS, nutrition data as dependent variables	HDDS, food expenditure, anthropometry
Ahmad et al 2016	Climate change and FS, Pakistan	Statistical model	Treatment model across different agroecological zones on climate and FS	Developed own principal components metric for FS
Obayelu and Onasanya 2016	Maize biodiversity and FS, Nigeria	Statistical model	Ag system variables used as explanatory factors for FS	Calories consumed
Salazar et al 2016	Smallholder farmers and FS, Bolivia	Statistical model	'pathways' from ag to FS	ELCSA

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Marsh et al 2016	Livestock vaccinations and girls schooling/human capital, Kenya	Statistical model	Estimated elasticities between specific ag technology (vaccinations) and food consumption expenditures	Food consumption expenditures
Azeem et al 2016	HH vulnerability and FS, Pakistan	Statistical model	Rural and urban HH comparison, hierarchical model and interesting focus on vulnerability	Calorie consumption
Szabo et al 2016	Soil quality and food security, Bangladesh	Statistical model	Combo of soil test data and HH survey data to identify linkages	Food expenditure, HH calorie availability
Ferdous et al 2016	Home gardens and food security, Bangladesh	Simulation model (Rangpur?)	Predicts food quality and consumption of specific foods	Vegetable consumption levels (kg/head) - observed
Beyene and Engida 2016	Irrigation investment and poverty Ethiopia	CGE model of public investment	Estimates total ag production per person as it relates to growth, poverty, ag production	Ag production per person
Gangwar et al 2016	Farming systems and extreme weather, India	Simulation (ICRISAT integrated farm system model)	Tracks ag yields under different weather challenges	Yields
Kassie et al 2015	Food security and gender, Malawi	Statistical model	Ordered probit model of food security, with partial ag explanatory vars (soil, rainfall)	Subjective/self-reported food security
Winter et al 2015	Jatropha as fuel crop and food security, Kenya	Simulation model	Examines jatropha value chain development and food security spillovers	Minimum subsistence requirements met
Modi 2015	Vegetable production and food security, South Africa	Statistical model	Ag variables as explanatory vars for food security	Food security value (own designed index of yields and consumption)
Sibhatu et al 2015	Production and dietary diversity for small farms, SSA + Indonesia	Statistical model	Compares production and diet across many ag systems	FVS, HDDS

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Karki et al 2015	Rural HH food self sufficiency, Nepal	Statistical model	Analyzing possible pathways to better food self-sufficiency for these areas	Food self-sufficiency
Niragira et al 2015	Crop patterns and food security thresholds, Burundi	Linear programming/optimization model	Optimizing across 15 different crops for best food security outcomes	Macronutrient self-sufficiency
Lázár et al 2015	Ag livelihoods, climate change and food security, Bangladesh	Simulation model (FAOCROPWAT)	FAO model modified to HH level to examine food security	Calorie intake, hunger periods
Louhichi et al 2014	Agri-food policy and food security, Sierra Leone	Optimization (AHM, FSSIM-DEV) non-separable model	Rice subsidies examined in particular as policy drivers for farm choices and welfare outcomes	Yields
Bashir et al 2014	Food demand policies for landless, Pakistan	Statistical model (partial equilibrium)	Policy impact pathways using PE models over time	Food demand (?)
Seaman et al 2014	Impact of climate change on poverty and FS, developing countries	Simulation model	Entitlement theory approach	?
Wossen et al 2014	Climate change and consumption, Ghana	Simulation model – agent based modeling	Looking at various drivers of consumption risk and poverty	Calorie consumption
Bacon et al. 2014	Analysis of factors associated with seasonal hunger among smallholder coffee producers Do coffee smallholders selling to fair trade markets and using more environmentally friendly farming practices experience shorter periods of seasonal hunger?	Statistical analysis Regression analysis	Combination of data from observations, interviews and focus groups with results from a survey of 244 cooperative members. Research site in northern Nicaragua Self-reported lean months	Seasonal hunger, proxied by: Percent of foods consumed in the household that were grown on the farm Was there a moment in which they could not meet their basic food need Which months are the most difficult to meet the basic food needs

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Adewumi and Animashaun 2013	This study examined the relationship among farming households' technical efficiency, dietary diversity and farm income in Kwara state, Nigeria.	Statistical analysis Descriptive statistics, stochastic frontier model, Household Dietary Diversity Score (HDDS) and Pearson Product Moment Correlation (PMCC)	Survey with 150 respondents across 3 geo-political zones Stochastic frontier model was used to estimate the respondents' technical efficiency while the dietary diversity score and farm income were analyzed with descriptive and inferential statistics. The Pearson Product Moment Correlation (PPMC) was used to assess the level of relationship among the indicators.	Household dietary diversity score
Sassi & Cardaci 2013	Analysis of the impact of the likely change in rainfall on food availability and access to food in Sudan.	Stochastic method and CGE model	The stochastic method, related to the Monte Carlo analysis, provides the likely changes in rainfall patterns and their probability of occurrence based on historical data. These results are at the basis of the scenarios simulated in a standard CGE model augmented with a stochastic component.	Food availability: local food production, quantities of commodities available (incl. imports) Food access: household income
Kokoye et al. 2013	Optimization of allocation of resources to different crops in the cotton zone in the Northern region of Benin (West Africa).	Optimization model	primary data collected from a sample of 71 farmers randomly selected in two villages in the Northern region of Benin (West Africa) optimization of gross margin of crops	Area cultivated per crop Gross margin of crops

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Djanibekov et al. 2013	the objectives of this study were (i) to investigate the role of interdependencies among commercial farms and semi-subsistence smallholders in the transfer of afforestation benefits, and (ii) to analyze the impacts and spillover effects of land use change to afforestation on agricultural production, income, consumption, and employment of rural households under conditions of decreasing irrigation water supplies.	Dynamic nonlinear programming model	The study area is the Khorezm region and three southern districts of the Autonomous Republic of Karakalpakstan located in the low-lands in Uzbekistan, Central Asia We modeled a cotton–grain commercial farm (hereafter referred to as farm) with an area of 100 ha, which is about the average size of this farm type after the latest land consolidation in the study area	Per capita food consumption Profit of farm Net incomes of rural households
Hoddinott et al. 2012	This report assesses the impact of the Productive Safety Net, Other Food Security and Household Asset Building Programs on food security, assets, and agricultural production	statistical analysis double-difference impact estimates using dose-response estimators assessment of impact in terms of changes over time between beneficiary and comparison households (“before/ after with/without” design)	Household questionnaires covering basic household characteristics; land and crop production; assets; nonagricultural income and credit; access to policy programs; consumption; health, shocks and perceptions; anthropometry	number of months that the household reports that it can meet its food needs (food gap) Caloric availability at the household level

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Thorlakson and Neufeldt 2012	This study explores whether and, if so, how agroforestry techniques can help subsistence farmers reduce their vulnerability to climate change	Statistical analysis Linear regression	Combination of household surveys, in-depth interviews, focus group discussions and field observations. Linear regression for data analysis. 2 research sites in Western Kenya Analysis of direct and indirect effects of agroforestry Direct effects: soil erosion, time spent collecting fuelwood Indirect effects: household wealth, food security, farm productivity	Farm production Proxies for a not very well defined "food security" indicator: Farm production, household wealth, male-headed household, education of household head, hold title deed to land, number of income sources
Stephens et al. 2012	investigation of interactions between natural resource-based poverty traps ad food security	Simulation System dynamics model Time horizon of 100 quarters	The CLASSES model describes conditions for a typical smallholder farm household in highland Kenya. These households follow a mixed livelihood strategy, growing some combination of annual food crops, perennial cash crops and perennial fodder crops, maintaining small livestock herds, engaging in wage labor, and receiving income transfers	Consumption shortfall (monetary value/quarter)
Molua 2012	establish household-level food security risks associated with climate variation, and how households respond to these risks in a patriarchal society such as in Northern Cameroon	Statistical analysis Multinominal logit model	Survey that generated information on the response and coping strategies to climatic variation; and the socioeconomic impacts of climate on households. Multinomial logit model to establish the determinants of the choice selection for climate risk coping options by households	Food availability Income expenditure on food according to season Proportion of food sources in household diets

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Qun ou et al. 2012	The goal of this study is to identify the key factors affecting food security between 1981 and 2005 and to provide some recommendations for improving food security	Statistical analysis Panel model	The panel data model includes cross-sectional and time-series information related to the factors influencing food security and the indicators used to measure food security. It describes not only the laws of sample data from various regions at a particular time, but also changes of the major factors and/or indicators of food security over time (1980-2005)	Food availability: grain production per capita Food access: purchasing power/per capita income
Di Falco et al. 2011	We examine the driving forces behind farm households' decisions to adapt to climate change, and the impact of adaptation on farm households' food productivity	Statistical analysis Simultaneous equations model	The climate change adaptation decision and its implications in terms of food productivity (our metric of food security) can be modeled in the setting of a two-stage framework. In the first stage, we use a selection model for climate change adaptation where a representative risk adverse farm household chooses to implement climate change adaptation strategies if it generates net benefits. In the second stage, we model the effect of adaptation on food productivity via a representation of the production technology.	Food productivity

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Dhakal et al. 2010	The first part of this study identified the effect of current forest policy on livestock production using survey data from 259 households in three Nepal hill districts. The second part used a forestry-agriculture integrated model to examine alternative land use policies that could increase household livestock holdings and income while maintaining the environmental services of the community forest.	Optimization model	In the model the community is structured as Z different income or 'well-being' groups with N households in each group. For modelling simplification, the community households are grouped into three income groups, rich (R), medium (M), and poor (P), based on sufficiency of household income from private landholdings to meet basic needs Objective function: maximization of community income subject to constraints on area, labor availability, employment opportunities, the need to meet basic food, heating and housing requirements, a restriction against making individual households worse off to maximize community income and government policies on community forest use	Average food production surplus or deficit by household type
Kaminski and Thomas 2011	This paper examines the impact of institutional changes in the cotton sector on the evolution of smallholders ' land-use decisions	Optimization Structural model Estimation of the system of ordered discrete variables by a bivariate ordered probit procedure	Hence, it is relevant to account simultaneously for food-security and income constraints in the optimization problem of the household. Representative household allocating farm land to two types of crops, food and cash crops	(no food security indicators – food security goal as determinant of land-use decisions)

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Murungweni et al. 2011	We studied characteristics and drivers of rural livelihoods in the Great Limpopo Transfrontier Conservation Area in southern Africa to assess the vulnerability of inhabitants to the different hazards they face	(Dynamic) simulation model Fuzzy Cognitive Mapping	The process involved four steps: (1) surveys and interviews to identify the major livelihood types; (2) description of specific livelihood types in a system format using fuzzy cognitive maps (FCMs), a semi-quantitative tool that models systems based on people's knowledge; (3) linking variables and drivers in FCMs by attaching weights; and (4) defining and applying scenarios to visualize the effects of drought and changing park boundaries on cash and household food security.	"food in household" "cash in household"

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Beyene and Muche 2010	The paper examines determinants of household food security among rural households in the Ada Berga district in central Ethiopia.	Statistical analysis Binary logistic regression model	A structured questionnaire was used to collect quantitative data through a household survey involving a total of 196 randomly selected households. The data analysis started with the conversion of the weekly consumption data into kilocalorie. The converted data were divided into household Adult Equivalent (AE). Following this, the amount of energy in kilocalorie (kcal) available for the household was recorded. Then after, the results obtained were compared with the minimum subsistence requirement per AE per day (which is 2,100 kcal). Dependent variable in logistic regression: probability of a household of being food secure	Household calorie acquisition
Suneetha and Yirgu 2010	examine the situation of food insecurity in the Mid-Deme watershed in Ethiopia	statistical methodologies such as food balance sheet, per capita food availability in kilocalories and multiple regression models	The Household Food Balance Model was used to quantify the net available food by each of the 194 sampled rural households To examine the statistical association of sixteen independent household variables with household food availability (dependent variable) a multiple regression model was used.	proportion of shortfall/surplus of the average daily dietary energy intake

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Magcale-Macandog et al. 2010	This study aimed to get a deeper understanding of the role of agroforestry in ensuring food security of farming households in the Philippine uplands.	Simulation model Bioeconomic modeling using WaNuLCAS (9 years)	Household survey with 300 farmers, focus group discussions, field experiment Bioeconomic modeling using the Water, Nutrient and Light Capture in Agroforestry Systems model WaNuLCAS WaNuLCAS is a process-based model of the water, nutrient and light capture in agroforestry systems. With the use of this model, the choice of tree species, their spacing and pattern and possible intercrop can be evaluated.	adequacy of farm harvest (corn and vegetables, fruits from trees) to meet their basic household needs → months with food abundance and scarcity/hunger Food expenditure and household income
Baran et al. 2010	Analysis of the consequences of different water management scenarios on rice, fish, crab and shrimp production in a province in Vietnam	Optimization Bayesian model 2000-2005	Model structure based on stakeholder consultation (model variables, model linkages, probabilities of interactions)	Rice production Fish production Household income
Ibrahim et al. 2009	Analysis of the food security status of farming households as well as optimization of farm plan to improve food security	Optimization Linear programming	Household calorie intake calculated from household consumption and expenditure data	Household calorie intake
Zheng et al. 2009	In this study, we explored the relative importance of soil parameters and management practices as sources of soybean yield variability among fields in a rural village of Northeast China associated with a severe drought growing season in 2007.	Statistical analysis: Classification and regression trees	In this study, regression trees were used to predict yield responses from soil and agronomic variables from all fields, and classification trees were used to identify the most important soil and management variables affecting yield from the three transects.	Soybean yield

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Tittonell et al. 2009	The objective was to investigate (i) current differences in resource use efficiencies and degree of crop-livestock interactions across farm types; and (ii) the impact of different interventions in different farm types on producing the desired shifts in productivity towards an ideal farm.	Dynamic, farm-scale simulation model	Combination of simulation models: FARMSIM (farm-scale decision making), FIELD (crop and soil modules), LIV-SIM (livestock), HEAP-SIM (dynamics of nutrients) Experimental data and, when possible, calibrated process-based models are used to generate functional relationships that are built into the various sub-models of FARMSIM.	Food self-sufficiency (capacity to meet the energy requirements of the household)
Kabura, Nyaga and Doppler 2009	This paper deals with household survey of cash crop smallholders in Murang'a District, Kenya. The paper focuses on how factors related to cash crops production affect food security.	Statistical analysis Principal component analysis	Survey with 120 households Principal Component Analysis (PCA) was used to construct a relative household food security index based on a range of food security related indicators. Upon construction, the index was converted into a qualitative variable and logistic regression models were then used to estimate the effect of smallholder tea and coffee production on household food security.	Food security index that represents a particular household's food security status in relation to all other households in the sample.

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Akinola et al. 2009	This study examined the socioeconomic impacts of the balanced nutrient management systems technologies on household incomes and food security of the adopting farmers in Nigeria.	Statistical analysis Two-stage least squares regression models	The analysis concentrates on the following four key linkages: Adoption of the BNMS technologies comprising various combinations of inorganic fertilizer and organic manure in different forms to household grown crop (maize). The reallocation of assets and inputs (labor, seed, land, etc.) as a consequence of adoption of BNMS technologies, resulting in improved yield and income of the household. The food consumption effects of increased productivity and income deriving from technical change and related changes in yield and income. The overall effects on poverty level which are manifest in increased livelihood assets (human, physical, social, financial and natural).	Calorie and protein intake Food expenditure

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Tingem et al. 2008	This study analyzes the potential of using dry/wet year predictions to reduce risk in subsistence agricultural production associated with climate variability at the site level.	Simulation model Combination of a weather generator with a crop growth model	CropSyst, a multiyear, multicrop, daily time step cropping system simulation model The main inputs are daily weather data and the model allows the user to specify management parameters such as sowing date, cultivar genetic coefficients, soil profile properties, fertilizer and irrigation management, and tillage.	Maize yield
Amede and Delve 2008	The objectives of this study were to: (i) characterize the current production system of various social groups in terms of human nutrition and income; (ii) develop cropping strategies that can improve cash income and household nutritional quality; and (iii) establish the implications of the change in cropping systems on other system components including soil erosion, livestock feed and crop water use at farm and higher levels.	Optimization model Linear programming	A multiple goal linear programming model was developed and used to analyze the different production objectives of cash income and/or human nutrition, through crop land allocation. Nutritional recommended daily allowance (RDA) according to the World Health Organization (WHO, 1999) was used to calculate household annual food demand. The objective functions in the model were either energy availability or cash income	Food self-sufficiency (capacity to meet the energy requirements of the household)

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Tesfaye et al. 2008	the aim of this paper is to identify the impact of small-scale irrigation on household food security based on data obtained from 200 farmers in Ada Liben district of Ethiopia in 2006	Statistical analysis Heckman's Two-step Estimation procedure	survey with 200 households Heckman's Two-step Estimation procedure	Food deficit/ food shortage months Food access: minimum food consumption expenditure per adult equivalent above which a household is considered to be food secure
Kassie et al. 2008	This article investigates the impact of stone bunds on value of crop production per hectare in low and high rainfall areas of the Ethiopian highlands	Statistical analysis Random effects models, stochastic dominance analysis, matching methods	Survey with 900 households regression approach that differentiates coefficients for adopters and nonadopters. We use parametric switching regression and nonparametric techniques to overcome the econometric problems and assure robust results. The nonparametric methods include stochastic dominance analysis and propensity score matching.	Crop yield
Hartter and Boston 2007	This paper introduces a conceptual framework to examine how individuals and households fulfill daily caloric needs and the aggregate effects on resource availability and consumption.	Dynamic simulation model	Development of an integrated conceptual model framework that can track fuelwood, agriculture, and livestock consumption to understand the processes of land-use change in rural communities. The daily human caloric requirement is what drives this model.	Food self-sufficiency (capacity to meet the energy requirements of the household)

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Yiridoe et al. 2006	An optimal whole-farm plan that incorporates traditional cropping of rice, jointly with livestock production was generated and then used to assess the economic implications of introducing an improved fallow rice cropping system in Northern Ghana	Optimization model Linear programming	The objective was to maximize total gross margin (i.e., farm returns above variable costs) from producing various crops and livestock, subject to farm resource constraints and other restrictions such as self-sufficiency in food production.	Crop production Farm income
Waithaka et al. 2006	The aim of this study was to improve understanding of farmers' conditions through the use of participatory approaches that incorporated simulation modelling, with a focus on farmer learning.	Simulation modeling with optimization	The methods used in this study integrated household survey data, participatory identification of suitable interventions, and bio-economic modelling using the Integrated Modelling Platform for Animal-Crop Systems (IMPACT) tool	Prices of staples and cash crops Farm income
Walker and Schulze 2006	The objective of this assessment was to investigate sustainability at the smallholder agro-ecosystem level in KwaZulu-Natal. Agroecosystem sustainability was assessed in regard to yield, soil organic carbon and nitrogen responses to a range of management practices and plausible climate scenarios.	Simulation model Crop model	In order to assess the sustainability of small-scale agroecosystems, a goal-orientated framework consisting of four steps was employed. The steps in the adapted goal-orientated system are identifying the goal, sustainability modelling, evaluation and management advice. For sustainability modelling in this assessment the CERES-Maize crop model was utilized.	Maize grain yield

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Thornton et al. 2006	quantify some of the effects of subdivision and land fragmentation on household livestock numbers and on food security in pastoralist communities in Kenya	Simulation models	Savanna is a spatially explicit computer simulation model that predicts forage production and quality based upon spatial data layers and settings that describe how plant populations grow. Joined to the Savanna model is PHEWS (Pastoral Household and Economic Welfare Simulator). PHEWS tracks the flow of cash and dietary energy in agro-pastoralist households using a simple set of rules.	Calories in households

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Kowero et al. 2005	The aim of this paper is to demonstrate that economic development goals in Southern Africa that seek to increase rural incomes, food security and environmental stability can be reconciled in the context of a set of activities and constraints on land, labor, food production, access to forest and other resources.	Optimization Weighted goal programming	The model employed is built following a generalized weighted goal programming methodology for woodlands in southern Africa. In this paper, WGP was chosen so that the goals of the different stakeholders could be considered jointly, thus avoiding giving preference to one goal to the disadvantage of the others. The typical household in each of the research sites was modeled in terms of major activities performed to meet daily needs. The activities require labor, land and woodland resources, which were identified as the main constraining factors. The household primary goals were found to be self-sufficiency in food (food security) and financial income to meet basic needs such as food, health, and education.	Daily energy requirements as goal in objective function Crop production

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Holden et al. 2005	This report presents a bioeconomic model of a less-favored area in the Ethiopian highlands. The data provide a valuable opportunity to analyze the relationships between population pressure, poverty, and land degradation, and to test policies for reducing vulnerability and improving sustainable management of the resource base.	Optimization Bio-economic model	dynamic non-separable household model that simultaneously integrates economic optimization in production and consumption with intertemporal environmental feedbacks, allowing for nonlinearities in constraints as well as the objective function. The bioeconomic model used in this study analyzes the combined effects of land degradation, population growth, market imperfections, and increased risk of drought on household production, welfare, and food security in Andit Tid. It is also used to assess the impact of increased access to credit for fertilizer, off-farm income, food-for-work interventions, and planting of eucalyptus trees as alternative strategies for local development.	Net food surplus/deficit in days per year
Bharwani et al. 2005	To investigate whether individuals, who adapt gradually to annual climate variability, are better equipped to respond to longer-term climate variability and change in a sustainable manner	Simulation Agent-based modeling (100 years)	The agent based model represents a case study farming community at an abstract level. The model consists of 50 poor and better-off farmer-agents with fields for planting and a market place at which to buy and sell produce	Crop yields

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Holden and Shiferaw 2004	This paper presents a bioeconomic model of a less-favored area in the Ethiopian highlands. The data provide a valuable opportunity to analyze the relationships between population pressure, poverty, and land degradation, and to test policies for reducing vulnerability and improving sustainable management of the resource base.	Optimization Bio-economic model	dynamic non-separable household model that simultaneously integrates economic optimization in production and consumption with intertemporal environmental feedbacks, allowing for nonlinearities in constraints as well as the objective function. The bioeconomic model used in this study analyzes the combined effects of land degradation, population growth, market imperfections, and increased risk of drought on household production, welfare, and food security in Andit Tid. It is also used to assess the impact of increased access to credit for fertilizer, off-farm income, food-for-work interventions, and planting of eucalyptus trees as alternative strategies for local development.	Net food surplus/deficit in days per year

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Alwang and Siegel 1999	In this paper, we investigate the sources of relative scarcity of labor and land in Malawi. The vicious cycle of poverty creates conditions where smallholders have limited access to liquid assets. In order to generate funds for pressing consumption and production needs, resource-poor households sell their labor to the detriment of on-farm productivity. Thus, finance constraints, exacerbated by food security concerns, contribute to the phenomenon of labor shortages among land-scarce farmers.	Optimization Linear programing model	simple linear programming model of representative smallholder households to investigate sources of relative scarcity of labor and land in Malawi. Several scenarios are run to reflect the multiple constraints faced by these farmers. One of the constraints in the objective function is food security (the food security constraint forces the household to produce at least one-half of its maize and groundnut needs).	Income from agricultural production Total household income

Author and Year	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Maatman et al. 1998	In this article we focus on the potential impact of a combination of rock bunds and zaï, a local technology to improve water infiltration and efficiency of manure application.	Optimization: Stochastic linear programming	A linear programming (LP) model for a farm household, representative for farm households on the Central Plateau, is used. The base model describes crop production decisions during one growing season, and consumption, storage and marketing strategies during the period from the beginning of the harvest period until the next harvest. The main objective of all strategies of the representative household is to try to prevent, or if that is not possible, to minimize shortages of energy and proteins during the target consumption year. If these shortages can be avoided, then a stock is kept for the harvest period of the next year. If these stocks are sufficient, then the revenues are maximized. If revenues are indeed obtained, a fraction is spent on a food security safety stock for the next year.	Food surplus/deficit in % of energy requirement

Table A3. Description of N=26 Papers Listing "Regional Food Security Models" in Search Terms and Meeting Selection Criteria

Source Reference	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Akter, S., & Basher, S. A. (2014). The impacts of food price and income shocks on household food security and economic well-being: Evidence from rural Bangladesh. *Global Environmental Change*, *25*(1), 150–162.	This paper examines the combined impacts of food price and income shocks on household food security and economic well-being in low-income rural communities in 12 districts of Bangladesh	Statistical (logit model); regional, dynamic (panel data)	Using longitudinal survey data of 1800 rural households from 12 districts of Bangladesh over the period 2007–2009, we estimated a three-stage hierarchical logit model to identify the key sources of household food insecurity.	The 2009/10 survey questionnaire included a module on self-assessed food security. (They state on p.153 that the questions are listed in Appendix B, but it is not part of the article.)
Antle, J. M., Stoorvogel, J. J., & Valdivia, R. O. (2014). New parsimonious simulation methods and tools to assess future food and environmental security of farm populations. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1639).	We motivate and illustrate our approach with an analysis of a critical challenge to agricultural progress in sub-Saharan Africa: declining agricultural productivity and persistence of high poverty levels, and the search for policy interventions that will achieve the win – win outcome of reversing both of these adverse trends. Case example is from Machakos.	Simulation (economics focus); regional application; dynamic	The model was designed to represent a generic farm household comprised crops, livestock, aquaculture and non-agricultural activities. Second, the adoption model was linked to distributions of quantifiable economic, environmental or social outcomes associated with the production system.	Proportion of farms below an income-based poverty line

Source Reference	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Bakker, C., Zaitchik, B. F., Siddiqui, S., Hobbs, B. F., Broaddus, E., Neff, R. A., … Parker, C. L. (2018). Shocks, seasonality, and disaggregation: Modelling food security through the integration of agricultural, transportation, and economic systems. *Agricultural Systems*, *164*, 165–184.	Food system based on characteristics of Ethiopia, a frequently food-insecure country; The Food-DECO model represents individual aggregated stakeholders as decision-makers within the agricultural, transportation, and economic systems.	Simulation (supply chain focus); national; dynamic	Captures important food supply chain components: along with the biophysical properties of crop; production, we explicitly model trade and food distribution in a way that accounts for infrastructure and geography. Capturing bilateral trade and food distribution enables us to consider transportation costs and regional price variations. Secondly, our model considers food access. Part of this consideration consists of food loss modelling, and another part of it includes disaggregating consumption by per capita income, age, and gender. The DECO model is formulated as an economic PE problem and solved as a Mixed Complementarity Problem (MCP).	Adult female caloric intake relative to baseline

Source Reference	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Chavez, E., Conway, G., Ghil, M., & Sadler, M. (2015). An end-to-end assessment of extreme weather impacts on food security. *Nature Climate Change*, *5*(11), 997–1001.	Here we present an 'end-to-end' methodological construct based on weather indices and machine learning that integrates current understanding of the various interacting systems of climate, crops and the economy to determine short- to long-term risk estimates of crop production loss, in different climate and adaptation scenarios. For provinces north and south of the Yangtze River in China	Simulation (biophysical focus); regional application with spatial disaggregation, dynamics not clearly indicated	**a**,**b**, Provide hydrological and crop modelling (**a**) and climate and weather modelling (**b**). **c**, Input from **a** and **b** is used to produce grid-to-province PDFs of yield loss captured by weather indices, conditional on large-scale interannual climate processes. **d**, The grid-level yield loss PDFs and yield response functions subject to GHG and technological scenarios from **c** are used to derive regional-level risk profiles of production loss.	Maize and rice yields
Cheng, K., Fu, Q., Li, T., Jiang, Q., & Liu, W. (2015). Regional food security risk assessment under the coordinated development of water resources. *Natural Hazards*, *78*(1), 603–619.	Analysis of four water resource utilization plans and three "climate conditions" in Heilongjiang Province (located in the eastern part of the mid-latitudes of Eurasia and is China's northernmost province)	Simulation (agent-based, water allocation focus); regional; appears to model a single year (2020)	The present paper utilizes an agent-based model of the complex adaptive systems (CAS) theory for dynamic simulation. Water supply agents 'optimize', but the objective function is not clearly specified. Model 'validation' is for single-point estimates?	Per capita grain production

Source Reference	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Cordero-Ahiman, O.-V., Santellano-Estrada, E., & Garrido, A. (2017). Explaining food insecurity among indigenous households of the sierra Tarahumara in the Mexican state of Chihuahua. *Spanish Journal of Agricultural Research*, *15*(1).	The objective of this research was to investigate the determinants of food insecurity among the indigenous communities of the Sierra Tarahumara in Mexico.	Statistical (logit model); regional; not dynamic	We estimated the main determinants of household food insecurity using both ordered logit model and binomial logit models. (Thus, not a biophysical simulation model.) The two predictive models applied suggest that: i) income is the most important determinant of access to food; ii) increased maize production improves food security; iii) farmers consume their seed stocks in times of food scarcity, and iv) households are food insecure when the householders are in casual employment.	Latin American and Caribbean Household Food Security Measurement Scale (ELCSA).
Dermody, B. J., Sivapalan, M., Stehfest, E., Van Vuuren, D. P., Wassen, M. J., Bierkens, M. F. P., & Dekker, S. C. (2018). A framework for modelling the complexities of food and water security under globalisation. *Earth System Dynamics*, *9*(1), 103–118.	We present a modelling framework for capturing regional and sectoral interdependencies and cross- scale feedbacks in the global food system that contribute to emergent water use patterns. The framework builds upon existing approaches in the fields of integrated assessment and hydrology and combines them via a multi-agent network of city agents and infrastructural trade links. We focus on cities because they are centres of food and water demand	Conceptual; potentially global; envisions dynamics	The framework integrates aspects of existing models and approaches in the fields of hydrology and integrated assessment modelling. The core of the framework is a multi-agent network of city agents connected by infrastructural trade networks.	None clearly defined

Source Reference	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Djebou, D. C. S., Price, E., Kibriya, S., & Ahn, J. (2017). Comparative analysis of agricultural assets, incomes and food security of rural households in Ghana, Senegal and Liberia. *Agriculture (Switzerland)*, *7*(5).	This article compares and examines the relationships among agricultural assets, incomes and food security in rural communities of Ghana, Senegal, and Liberia.	Statistical (logit model); multi-national; not dynamic	The study used a multivariate logistic (statistical) model with household data, then evaluated how agricultural assets affect the food security status of rural households in Ghana, Senegal and Liberia. Explanatory variables include land size, irrigation, fertilizer and tractor--most of which appear endogenous?)	Queries considered for assessing the food security status of each of the 1483 households (HHDs). (Five questions, in the vein of FIES; if 2 were answered positively, coded as "food insecure")
Dorosh, P. A., Rashid, S., & van Asselt, J. (2016). Enhancing food security in South Sudan: the role of markets and regional trade. *Agricultural Economics (United Kingdom)*, *47*(6), 697–707.	This article examines options for enhancing food security in South Sudan, focusing mainly on ways to maintain availability of cereal supply and price stability.	Partial Equilibrium, multi-commodity (economic focus); national; not dynamic	We utilize a simple partial equilibrium model of the South Sudan cereal market. The model assumes that the South Sudan and the Uganda cereal markets are cointegrated; We model four commodities: sorghum, maize, wheat, and rice; Total household income is calculated as the value of cereal production scaled up with a factor to account for downstream multiplier effects on processing, marketing, and consumption; Household demand is modeled as a log-linear function of household per capita income and market prices;	(Aggregate) cereal consumption

Source Reference	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Guillaume, J. H. A., Kummu, M., Porkka, M., & Varis, O. (2014). A conceptual model to guide exploration of global food-water security. In *Proceedings - 7th International Congress on Environmental Modelling and Software: Bold Visions for Environmental Modeling, iEMSs 2014* (Vol. 4, pp. 2210–2217).	Macro-level generic conceptual model	Conceptual; potentially global; does not discuss dynamics	More a logical process than an empirical model. Ultimately assesses whether food demand (in water equivalents) equals food supply.	Does food supply equal food demand?
Haggblade, S., Me-Nsope, N. M., & Staatz, J. M. (2017). Food security implications of staple food substitution in Sahelian West Africa. *Food Policy*, *71*, 27–38.	This paper develops a multi-market simulation model to evaluate the impact of common production and world-price shocks on food consumption of vulnerable groups in Sahelian West Africa.	Partial Equilibrium, multi-commodity (economic focus); national (based on Mali); not dynamic	The paper develops and applies a multi-market (static, supply and demand) simulation model; Structurally, the present model includes four household groups and five commodities	Calories per capita per day, by household group

Source Reference	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Harttgen, K., Klasen, S., & Rischke, R. (2016). Analyzing nutritional impacts of price and income related shocks in Malawi: Simulating household entitlements to food. Food Policy, 60, 31–43.	In this paper we adopt a very simple micro-based simulation approach to analyze how changes in prices of specific food groups, such as maize prices or prices for staple foods, as well as how negative short-term household level income shocks affect the entitlements to calorie consumption of individuals and how these changes affect overall food poverty.	Simulation (heavily based on survey data relationships); national, dynamic (covers 12 specific months)	The simulations done in this paper largely build on the parametric estimate of the income-food consumption linkage, which we derive from household survey data. We take this relationship to estimate the impact of negative income shocks (for some simulations induced by price changes) on food availability. In particular, we apply a simple OLS regression of calories per day and per capita on log household income/expenditure	We define a household (and all its members) as **food deprived** if its amount of consumed calories per day falls below the (age and sex specific) food requirement threshold for that household. Overall food poverty is then calculated as the percentage of households or individuals that fall below their food poverty thresholds. Thus, calories per day and per capita, based on household level data
Larson, D. F., Lampietti, J., Gouel, C., Cafiero, C., & Roberts, J. (2014). Food security and storage in the Middle East and North Africa. *World Bank Economic Review*, *28*(1), 48–73.	In this paper, we describe a rational expectations model of competitive storage and trade, based on wheat markets for the Middle East and North Africa and the rest of the world. We use the model to quantify the effects of a strategic inventory policy designed to protect consumers in the region from very high prices.	Simulation; regional; dynamic (time horizon not clearly stated)	Stochastic stylized model of supply and demand for wheat in MENA and ROW	Coefficient of variation for prices

Source Reference	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Lázár, A. N., Clarke, D., Adams, H., Akanda, A. R., Szabo, S., Nicholls, R. J., … Moslehuddin, A. Z. M. (2015). Agricultural livelihoods in coastal Bangladesh under climate and environmental change - A model framework. *Environmental Sciences: Processes and Impacts*, *17*(6), 1018–1031.	This study is based on the south-western coastal zone of Bangladesh, where there is a tidal influence. Here an integrated approach has been proposed to develop a simulation model to support agriculture and poverty-based analysis and decision-making in coastal Bangladesh.	Simulation (integrated); regional with spatial disaggregation, dynamic (2011-2050)	An extended version of the FAO's CROPWAT agriculture model has been integrated with a downscaled regional demography model to simulate net agriculture profit. This is used together with a household income–expenses balance and a loans logical tree to simulate the evolution of food security indicators and poverty levels.	The food insecurity indicator is the calorie intake-based (kcal per capita per day) hunger period length (i.e. the number of months in a year, when the calorie intake is less than 1805 kcal per capita per day). The 2122 kcal per capita per day had been used as a food poverty threshold for Bangladesh.

Source Reference	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Lloyd, S. J., Sari Kovats, R., & Chalabi, Z. (2011). Climate change, crop yields, and undernutrition: Development of a model to quantify the impact of climate scenarios on child undernutrition. *Environmental Health Perspectives*, *119*(12), 1817–1823.	We developed a model for estimating future undernutrition that accounts for food and nonfood (socioeconomic) causes and can be linked to available regional scenario data. We estimated child stunting attributable to climate change in five regions in South Asia and sub-Saharan Africa (SSA) in 2050.	Simulation (heavily based on statistical relationships); global; not dynamic (single year 2050)	We used current national food availability and undernutrition data to parameterize and validate a global model, using a process-driven approach based on estimations of the physiological relationship between a lack of food and stunting. We estimated stunting in 2050 using published modeled national calorie availability under two climate scenarios and a reference scenario (no climate change). Underweight was estimated using an equation developed by Smith and Haddad (2000), which is driven by per capita calorie availability and socioeconomic indicators: the ratio of female to male life expectancy, female enrollment in secondary education, and access to improved water supply. Future per capita calorie availability was estimated by modeling crop yield and global food trade.	Underweight (stunting) distribution
Mainuddin, M., Kirby, M., & Hoanh, C. T. (2011). Adaptation to climate change for food security in the lower Mekong Basin. *Food Security*, *3*(4), 433–450.	This paper examines the impact of climate change on rice production in the lower Mekong Basin, evaluates some widely used adaptation options, and analyses their implications for overall food security by 2050.	Simulation (biophysical focus); regional application with spatial disaggregation, dynamic (2011-2050)	The 'AquaCrop' model developed by the Food and Agricultural Organization (FAO) of the United Nations was used to study the impact of climate change on the yield of rainfed and irrigated rice grown in the Basin.	Rice yields and calculates production per capita required to meet expected demand in 2050

Source Reference	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Mason-D'Croz, D., Vervoort, J., Palazzo, A., Islam, S., Lord, S., Helfgott, A., … Lipper, L. (2016). Multi-factor, multi-state, multi-model scenarios: Exploring food and climate futures for Southeast Asia. *Environmental Modelling and Software*, *83*, 255–270.	In this paper, we present scenarios for southeast Asia developed by regional stakeholders and quantified using two global economic models, GLOBIOM and IMPACT, in interaction with stakeholder-generated narratives and scenario trends (similar to 2017 paper)	Simulation (integrated); global with national disaggregation; dynamic (to 2050—at five-year intervals?)	The two economic models used were IIASA's Global Biosphere Management Model (GLOBIOM) and IFPRI's International Model for Policy analysis of Agricultural Commodities and Trade (IMPACT); similar to 2017 paper	Rice and sweet potato yields; index of "total crop production"
Montella, R., Kelly, D., Xiong, W., Brizius, A., Elliott, J., Madduri, R., … Foster, I. (2015). FACE-IT: A science gateway for food security research. *Concurrency Computation*, *27*(16), 4423–4436.	We have described FACE-IT, a new IT infrastructure designed to accelerate existing disciplinary research and enable information transfer among traditionally separate fields.	IT configuration to link simulation models;	Not a simulation model, an IT module linking different models	Compares yields from models
Moore, N., Alagarswamy, G., Pijanowski, B., Thornton, P., Lofgren, B., Olson, J., … Qi, J. (2012). East African food security as influenced by future climate change and land use change at local to regional scales. *Climatic Change*, *110*(3–4), 823–844.	This study focused on the East African countries of Kenya, Uganda, Tanzania, Burundi, and Rwanda	Simulation (biophysical focus); multi-national; dynamic (to 2050 decade)	Address the shortcomings of coarse spatial resolution assessments of the impact of climate change on food security through high resolution studies of climate change, coupled to a process-based crop simulation model.	Maize yields

Source Reference	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Oehmke, J. F., Young, S. L., Bahiigwa, G., Keizire, B. B., & Post, L. A. (2018). The Behavioral-Economics Basis of Mutual Accountability to Achieve Food Security. *Politics and Policy*, *46*(1), 32–57.	Stylized African agricultural development setting	Simulation (simple agent-based); single region; dynamic (500 'generations')	Stochastic three-person prisoner's dilemma game simulated 10,000 times for a 500-year period.	Stylized game theory payoffs, none empirically based
Paeth, H., Capo-Chichi, A., & Endlicher, W. (2008). Climate change and food security in tropical West Africa - A dynamic-statistical modelling approach. *Erdkunde*, *62*(2), 101–115.	Regions of Benin	Statistical (biophysical focus); Regional with spatial disaggregation (Benin); dynamic (base data 1978-2003, simulated values at 5-year intervals through 2025)	Statistical model linking climate variables to crop yields using least squares and stepwise regression	Crop production and yields
Palazzo, A., Vervoort, J. M., Mason-D'Croz, D., Rutting, L., Havlík, P., Islam, S., … Zougmore, R. (2017). Linking regional stakeholder scenarios and shared socioeconomic pathways: Quantified West African food and climate futures in a global context. *Global Environmental Change*, *45*, 227–242.	In this paper, we present scenarios for West Africa developed by regional stakeholders and quantified using two global economic models, GLOBIOM and IMPACT, in interaction with stakeholder-generated narratives and scenario trends and SSP assumptions.	Simulation (integrated); global with national disaggregation; dynamic (to 2050)	GLOBIOM and IMPACT are global partial equilibrium models with a detailed representation of the agricultural sector.	Percent deviation in kilocalorie availability per capita per day from 2010 values

Source Reference	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Springmann, M., Mason-D'Croz, D., Robinson, S., Garnett, T., Godfray, H. C. J., Gollin, D., … Scarborough, P. (2016). Global and regional health effects of future food production under climate change: A modelling study. *The Lancet*, *387*(10031), 1937–1946.	We linked a detailed agricultural modelling framework, the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), to a comparative risk assessment of changes in fruit and vegetable consumption, red meat consumption, and bodyweight	Simulation (integrated); global with national disaggregation; appears to be static (only 2050 results reported)	The IMPACT model estimates commodity-specific food availability at the national level, which we used in a comparative risk assessment to analyse changes in the exposure of dietary and weight-related risks. For the dietary risk assessment, we converted the food availability estimates for fruit and vegetables and for red meat into food consumption estimates by using regional data about food waste at the consumption level, combined with conversion factors into edible matter.	National food availability (production + trade?) was converted to a consumption estimate using waste and edible portion. For the weight-related risk assessment, we estimated **changes in weight as shifts in the baseline weight distribution by using the historical association between national food availability and** mean body-mass index (BMI).
Tabeau, A., van Meijl, H., Overmars, K. P., & Stehfest, E. (2017). REDD policy impacts on the agri-food sector and food security. *Food Policy*, *66*, 73–87.	This paper studies the impact of REDD policies on the agri-food sector and food security with a global CGE model called MAGNET using a scenario approach. It focuses on the restrictions on agricultural land expansion within the REDD policy package.	Simulation (economics focus/CGE); global with national disaggregation; static (2050)	The MAGNET model is a multi-regional, multi-sectoral, applied general equilibrium model based on neo-classical microeconomic theory. It is an extended version of the standard Global Trade Analyses Project (GTAP) model	In this paper we focus on **two of the four dimensions of food security**: food availability – Is there enough food? – and food access. Availability is a production index, access is an index of per capita consumption

Source Reference	Setting	Model Type Summary	Model Discussion	Food security Indicators (Red is more directly related, blue not so related)
Wailes, E. J., Durand-Morat, A., & Diagne, M. (2015). *Regional and national rice development strategies for food security in West Africa*. *Frontiers of Economics and Globalization* (Vol. 15).	We examine one of these approaches: increased production and self-sufficiency as a means to address food insecurity in West Africa. "The food security objective of CARD is to double rice production in West Africa by 2018"	Partial Equilibrium, single commodity (economic focus); global with regional/country disaggregation; dynamics not clearly indicated	The analytical framework is based on two global rice models: the Arkansas Global Rice Model (AGRM) and the RiceFlow model. AGRM is an econometric structural model based on estimated equations of area harvested, crop yield, per capita consumption, trade, and stock behavior. All countries in the world are included either individually (44 major rice producing/consuming countries) or regionally	Only aggregate production and consumption at national level (thus, one element of availability and access)
Wu, J., Zhang, J., Wang, S., & Kong, F. (2016). Assessment of food security in China: A new perspective based on production-consumption coordination. *Sustainability (Switzerland)*, *8*(3).	This article sets up a multidimensional coupling assessment index system and model and carries out assessment of the food security level and the warning status of China between 1995 and 2012. Elements of the index include quantity coordination, structural coordination and regional coordination.	Statistical (coordination focus); national (based on regional data); dynamic (1995-2012 data)	Index calculation only, data from 1995-2012	The index of coordination is taken to be a sort of indicator of food security, but it is not consistent with other measures and should be considered only an intermediate "system function" type indicator, given that its correlation with other more specific indicators is not done.

Appendix 2. Brief Discussion of RHoMIS Food Insecurity Indicators

We believe that the RHoMIS approach has great potential to facilitate the incorporation of food security indicators into agricultural systems models. However, it is worth noting that the methods used for the collection of these indicators depart in potentially important ways from those used in validating the original indicators. Hammond et al. (2017) describe the process RHoMIS uses for collecting the data for HDDS and HFIAS. The HDDS departs from standard practice by using long-term (and seasonal) recall rather than 24-hour recall as in the validated scale. Any divergences for the HFIAS indicator are not explicitly described, but FIES often utilizes statistical post-processing based on Item Response Theory (IRT) to develop consistent comparative measures of the severity of food insecurity (Ballard et al., 2013), and these are not mentioned or described in Hammond et al. (2017). The departure of the RHoMIS methodology from standard methodology for collecting data on and calculating the HDDS and HFIAS is potentially problematic depending on the use of the information.

Shifting to a food frequency approach for measuring diet diversity is not new. The WFP's Food Consumption Score (FCS) indicator takes a similar approach. The FCS combines data on dietary diversity and food frequency using 7-day recall data. Respondents report on the frequency of household consumption of 8 food groups. The frequency of consumption of these groups is then multiplied by an assigned weight for each group and the resulting values are summed to obtain the FCS. While there appears to be no weighting for the RHoMIS diet diversity indicator, extending recall periods from 24 hours to 4 weeks will almost certainly reduce between-individual variation and thus make it more difficult to detect differences in diversity within a sample. Our assessment is that accuracy may note be markedly affected because different recall of frequency of consumption over a longer period vs. recall of exact diet over a short period of time, because both subject to errors and can present useful information of usual diet intake. Some of the discussion related to the FCS reported in an earlier article would also be relevant to this indicator, especially consideration of cut-offs and baseline diets in a region:

"…the cutoffs for determining levels of food insecurity severely underestimated food insecurity as measured by calorie consumption per capita and that the weightings of food groups did not improve associations with energy intake (57). The cutoffs for the FCS may

also need to be adjusted upwards in situations where nearly all households consume sugar and oil regularly, effectively establishing a minimum FCS of 7 for all households (56)…In addition, the positive associations observed between the FCS and household calorie consumption do not necessarily equate to positive associations with nutrient intakes." (Jones et al, 2013).

Overall, though, we suggest caution in interpreting the results of this diet diversity indicator without additional validation work done to confirm that it is measuring what it purports to measure.

As for the adapted HFIAS, we have not seen used a continuous 0-27 point score used for the HFIAS (though it is reported as an option in the guidance manual for the indicator). Rather, what is much more commonly used is developing categorical variables based on the individual responses to the 9 questions of the scale. These categories reflect experiences of the distinct domains of food insecurity captured by the HFIAS (i.e., anxiety, food quality, food quantity). These differences would be glossed over in a continuous score, therefore not reflecting the underlying theory of the indicator as well, nor allowing for a clear interpretation of the score. In addition, the changes made to the response options, and in particular, the variable shift in the recall period (i.e., the "worst month" could have been quite long ago, and could also be variable by respondent thus calling into question recall bias and ability to compare a standard recall window across respondents) make us question how to interpret this indicator without additional validation work being done.