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Contributions of livestock-derived foods to nutrient supply under changing demand in low- and middle-income countries

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ABSTRACT

The potential to use large-scale dietary transformations to meet nutritional needs of the world's poorest populations may have been largely overlooked. A case study is presented of food nutrient supplies in eight selected countries within the context of their growing demand for livestock-derived food (LDF). For almost all the countries and under a range of scenarios of economic and climatic change in 2050, we find that per capita protein supply from LDF will increase relative to that from plant sources. Survey data indicate higher LDF consumption, up to 22%, among children in households that keep livestock compared to others. However, projections that four of the selected countries will import at least 40% of their LDF protein highlight the opportunity to increase livestock sector production and the potential to develop smallholder inclusive policies.

1. Introduction

Substantial progress has been made in the past decades in addressing the most extreme forms of hunger. The share of undernourished people decreased from nearly one quarter of the global population in 1970, to about 15% in 2000, and around 11% in 2014–2016. The most recent reports however indicate that still around 815 million people remain chronically undernourished (FAO/IFAD/UNICEF/WFP/WHO, 2017), justifying a sustained focus on energy intake deficits. In parallel, the prevalence of other forms of malnutrition, including overconsumption of nutrients, and micronutrient deficiencies, lead to rising concerns about the composition of human diets, in both quantity and quality terms. This is of particular relevance in low- and middle-income countries (LMICs) where income growth, urbanization, and related factors have been driving a dietary and lifestyle shift towards increased consumption of foods high in fat and sugar content, resulting in higher rates of diet-related diseases as had been previously associated only with wealthier countries (Walker et al., 2005).

Although often linked to public health issues such as obesity and food-related non-communicable diseases, the factors driving dietary transitions may also present opportunities for increased consumption of nutrient-dense foods such as animal-source foods, fruits, and vegetables (Popkin et al., 2012). Increased intakes of animal-source foods are known to provide critical benefits to nutritionally vulnerable groups such as children, women of reproductive-age, or the elderly, in poor countries (Murphy and Allen, 2003; Randolph et al., 2007; Grace et al., 2018). Large-scale dietary transitions also contribute other significant transformations in the global food and agricultural system. To better identify intervention options for the livestock sector that meet objectives related to food security, livelihoods and nutrition, there is a need to better understand the nature and impacts of these dietary transitions.

Scenario analysis of the growing demand for animal source foods – i.e., meat, milk and eggs, as well as fish and other seafood - have indicated quite significant impacts at global level, on food prices and natural resource systems (e.g., Kobayashi et al., 2015; Rosegrant et al., 2013), as well as on rural livelihoods and incomes (Herrero et al., 2014). Not much attention has however been paid to how the dietary transition is affecting nutrient availability or intake within the countries in which demand for livestock food product types is expanding, or how these changes will transition under different macro-environments. It is also not well understood how the changing demand will impact on nutritional or livelihood outcomes of smallholder livestock producers within the affected countries. Such gaps in the knowledge have important consequences for development outcomes, and thus for the designing of relevant policy, and need to be explored. Of all animal-source food types, livestock-derived foods (LDF), i.e., meat, milk and eggs and their derived products, are known to account for about 80% of production and consumption volumes globally (FAO, 2015). These LDF are the focus of this paper.

In this paper, we assess the contribution of livestock to the food and

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nutrient supply of LMICs, presenting a case study of eight countries. Using the global economic model, IMPACT, we compare alternative scenario projections of countries' food and nutrient supply in 2050 against equivalent indicators for a baseline year of 2010, and a reference scenario of moderate economic growth to 2050. To highlight potential distributional effects of the macro model outputs, we review nationally-representative household survey data on livestock ownership patterns and the consumption of LDF among children in households of different wealth categories. This latter analysis allows us to make early inferences about potential linkages between the production and demand of LDF in the future, and livelihood and nutrition improvements of smallholder households that keep livestock.

2. Livestock's contributions to nutrition and livelihoods in LMICs

LDF and fish have been described as high biological value proteins, including all nine of essential amino acids needed by humans, some of which are very limiting in plant protein sources (USDA and USDHS, 2010). Even small increases in consumption of these foods have been shown to make meaningful impacts on the health outcomes of children in developing countries, given the good quality of their protein and the content in bio-available micronutrients (e.g., iron, zinc) critical for reducing stunting and securing normal cognitive development (Murphy and Allen, 2003). In LMICs, recognition of the importance of livestock-keeping and production of LDF as instruments for addressing wide-reaching nutritional needs is further motivated by the role of the livestock sector already as a major provider of livelihoods and incomes to millions (Staal et al., 2009; Randolph et al., 2007). In addition, LDF are considered key to improved nutrition during the first 1000 days of children, from conception up to two years (Grace et al., 2018).

However, the evidence is mixed as to whether, and how, increased ownership of farm animals and household production of LDF translates to higher intakes of LDF within livestock-keeping smallholder households, or to improvements in household nutrition and health. While some studies have shown higher LDF consumption or improved child nutrition (Hoddinott et al., 2015; Dessie et al., 2003; Azzarri et al., 2015), others point to no such associations (Mosites et al., 2016, 2015). For the most part, it remains to be tested if nutrition benefits are to be expected from increased livestock production or ownership over the long-run, and under different scenarios of global change.

Starting from the seminal work by Delgado et al. (2001), quantitative scenario analysis have been used to assess the potential impacts on food security, nutrition and health, of the expanding consumption and production of livestock in LMICs (e.g., Rosegrant et al., 2013; Springmann et al., 2016). These studies have looked at changes related to kilocalorie availability and intakes, including their effects on undernutrition (e.g., measured as risk of hunger and prevalence of underweight among young children as in Rosegrant et al., 2013), and overnutrition (e.g., measured as mortality rates linked to dietary and weight-related risk factors as in Springmann et al., 2016).

The contribution of livestock to countries' supply of essential nutrients, and to the incomes and livelihoods of vulnerable populations, as well as indications of how these will fare under factors of global change, are still important elements of the international development discourse (Thornton, 2010; Thornton et al., 2009). In regions such as in the Sahel and Horn of Africa, where livestock production activities are mainstays of the economy, prospects for increasing or even maintaining current levels of LDF production in the coming decades may be increasingly hampered by threats of climate change, amongst others (McDermott et al., 2013). While international trade offers alternative channels for meeting growing nutrient requirements in LMICs (Havlík et al., 2014), trade-based strategies typically require the efficient functioning of cross-border food supply networks, a condition that does not always exist (Williams et al., 2006). In addition, net-exporting countries have been known to stem food exports during times of scarcity, posing increased threats of food unavailability to the net-importers (Puma et al., 2015). Local production is thus still considered key, in many LMICs, to meeting future demand for important food types like LDF, as well as for attaining other objectives for rural development (IFAD, 2010).

Studies such as Herrero et al. (2014) identified investments to increase livestock productivity and production in LMICs as strategic for sector development. Intervention programs such as those that promote increased milk and egg production, may be particularly favored in poorer countries, as smallholder producers can consume part of what they produce without the need to slaughter or sell a large animal (Kryger et al., 2010). However, a key question remains as to whether smallholder producers, who will be the primary targets of such pro-poor livestock sector development strategies, can compete effectively against industrial livestock producers. It is not even known if smallholders will at all remain relevant to countries' food production in the future (Collier and Dercon, 2014).

3. Framework to assess contributions of LDF to food supply: an eight-country study

The analyses in this paper has two parts, I) economic modeling of the global food and agricultural system, to generate baseline data on food supply consistent with FAO national statistics for 2010 as well as scenario projections of the same indicators in 2050; and II) assessment of household level data from the Demographic Health Surveys (DHS) to understand patterns of livestock ownership across wealth distributions, and the consumption of LDF among children in livestock-owning households. Eight countries are included in the study, namely Burkina Faso, Ethiopia, India, Kenya, Nicaragua, Tanzania, Uganda and Vietnam, representing a range of population, income, urbanization and economic growth levels (Table 1). National statistics show that protein supplies from LDF in the study countries ranged between 8 and 23 g per person per day (g/capita/day), somewhat below the global average of 27 g/capita/day, and well below the average of 60 g/capita/day in the European Union (year 2013) (FAO, 2015), presenting ample

Table 1
Population, income, urbanization and per capita protein supply from LDF in the study countries, year 2010.

	Population (millions)	Population in urban areas (%)	Urbanization growth rate (%)	GDP per capita (US dollars)	GDP, annual growth rate (%)	Proteins from LDF (g/pers/dy)
Burkina Faso	16	26	4.4	600	5.9	10.4
Ethiopia	88	17	1.8	360	8.5	8.8
India	1230	31	1.2	1320	7.1	10.2
Kenya	40	24	1.9	980	4.0	16.1
Nicaragua	5.7	57	0.5	1560	3.0	18.4
Tanzania	46	28	2.6	710	6.5	7.6
Uganda	33	15	2.0	590	7.00	8.9
Vietnam	87	30	2.5	1370	6.6	21.0

Source: Authors' collation using data from United Nations (2014), WorldBank (2016), and FAO (2017). Urbanization rate is average 2000–2010; GDP per capita is average 2009–2011. Other estimates are 2010.

opportunity for sector expansion. An underlying assumption is that in the case study countries, as in many LMICs, changes in the factors influencing the demand for LDF, will trigger associated changes across the livestock sector (Delgado et al., 2001). Investment in the livestock sector of these countries is, in particular, thought to hold much potential for both higher incomes of poor producers, and improved nutrition of poor consumers (ILRI, 2011).

3.1. Modeling countries' food supplies in 2050

Our forward-looking analyses assessed estimates of national demand, production and trade, in aggregate and as per capita supplies, of crop-derived (CDF) and livestock-derived foods (LDF) in the eight study countries in 2050. This analysis used IMPACT (the International Model for Policy Analysis of Agricultural Commodities and Trade), a multimarket sectoral model that has been widely applied to answer questions relating to investment and policy in the global agricultural sector (Robinson et al., 2015). IMPACT, which relies on a system of demand and supply equations, accounts explicitly for output prices, population growth and income growth in its calculation of demand for agricultural commodities, and for input and output prices of agricultural commodities, technological change and environmental stresses in its calculation of production levels. Transitions such as urbanization and changing consumer preferences are also incorporated more indirectly into the simulation model, through time-dependent changes in elasticities, i.e., the responsiveness of demand or supply to changes in income or price. IMPACT solves for country-level solutions that equate supply and demand across the globe. It tracks a country's trade with the rest of the world, making it possible to report on the direction and volume, but not the origin or destination of trade flows. Total domestic demand for agricultural commodities consists of household food demand, demand for use as input into other agricultural activities, and demand for industrial uses.

We analyzed the model's results on country demand, production and trade of different LDF products for a set of pre-determined scenarios of global economic and environmental change. To maintain the focus on human nutritional benefits, we included the household/food component of aggregate commodity demand, but not the non-food components, for example demand for livestock feeds or for industrial bio-stock. Food supply corresponding to the total demand from households included what is available from local production, as well as through imports. A positive (negative) net trade value implies that a country's production of a commodity is higher (lower) than its household demand for the same, leaving it in a net food export (import) position. Estimates of food demand and supply were calculated on national aggregate and per capita basis, with 2010 selected as the initial model year, calibrated in IMPACT using national FAO statistics, against which the generated outcomes for 2050 could be compared (FAO, 2015). The IMPACT model outputs were assessed for four scenarios of economic growth and climate change in 2050.

3.1.1. Plausible scenarios of 2050

The four scenarios of economic or climate conditions in 2050 (Table 2), included in the analysis originate from the Shared Socioeconomic Pathways (SSP) and Representative Concentration Pathways (RCP) of the Intergovernmental Panel on Climate Change (IPCC). The SSP are a set of narratives that together describe plausible ranges of uncertainty facing global socio-economic development; differing in their projections of a country's population and income. The RCP are trajectories of greenhouse gas concentrations that have been quantified using a range of earth system models (ESM) (Robinson et al., 2015); providing alternative climate data (e.g. temperature) driving crop yield and production responses. Three of the scenarios are from the SSP, i.e. low, moderate and high economic growth. The fourth scenario combines SSP and RCP and simulates how future climate change (CC) would impact the moderate growth scenario. The chosen RCP CC scenario is the most extreme level of potential climate impacts against which trends and interventions can be tested in IMPACT. All four scenarios used in the analysis are extended results of model simulations first used in Sulser et al. (2014).

All generated projections for 2050 are compared against the baseline year 2010. We use the medium economic growth scenario as our reference scenario to assess plausible transitions of countries' food supply and demand over time for each country. The other three scenarios, i.e. low economic growth, high economic growth, and climate change, give an indication of a range of future outcomes deviating from this medium growth scenario. These (three) alternative scenarios represent a spread of potential environmental and socio-economic stressors facing LMICs that policymakers will need to consider in formulating robust policies for food security and development (Vervoort et al., 2014).

3.1.2. Food nutrient equivalents

Food quantities generated by IMPACT were translated to nutrient equivalents using the food composition database (FCD) developed by the United States Department of Agriculture (USDA, 2015). Although country- and region-specific food composition tables exist that may be adapted to the precise nutrient profiles of the foods of each individual countries in the study (FAO, 2017), the use of USDA's FCD alone was considered sufficient. Within the global economic model, agricultural commodities are assumed to cross borders without considerations for potential country-specific influences on food nutrient contents. We have chosen to report nutrient supply in terms of proteins, iron, and vitamin A, all supplied in relative abundance from LDF. As protein is the most important contribution from LDF to macro-nutrient supplies (USDA, 2015), its use was considered a more relevant measure of the contribution of LDF to food nutrients than, example, calories. Deficiencies in Vitamin A and iron are leading causes of deaths and of children failing to reach their developmental potential in LMICs (Randolph et al., 2007; Black et al., 2013), motivating our use of these micronutrients to represent LDF contributions to total micro-nutrient values.

Table 2
Scenarios of global change included in the study.

SSP code[a]	Scenario name	Scenario description
SSP1-NoCC	High growth	Global sustainable development realized, evident by high rates of economic growth and declining population growth. Observations on effects of climate change are a continuing of historical trends.
SSP2-NoCC[b]	Reference/moderate	Middle-of-the-road development with moderate rate of economic growth and a moderate slowing of population growth. Observations on effects of climate change are a continuing of historical trends.
SSP3-NoCC	Low growth	Worsening conditions of global development, evident by low rates of economic growth and higher population growth. Observations on effects of climate change are a continuing of historical trends.
SSP2-HGEM	Climate change	Middle-of-the-road development i.e., SSP2, with CC impacts included. Significant challenges to global climate change adaptation and mitigation according to the Representative Concentration Pathway (RCP) 8.5 and using the earth system model HADGEM.

[a] The SSP codes and descriptions are from Robinson et al. (2015).
[b] The reference scenario is the middle-of the-road Shared Socioeconomic Pathway (SSP) that represents a continuing of historical trends.

Table 3
Projections of household aggregate demand for selected LDF and CDF in the study countries in 2050, under the reference scenario.

Food demand[a] in 2050 in '000 MT (% change from 2010 to 2050)	Poultry meat	Pig meat	Cattle meat	Sheep & goat meat	All meat[b]	Eggs	Milk	All LDF[c]	Cereals & grains	Pulses & legumes	Roots & tubers	Fruits & vegetables	All CDF[a]	Total food demand
Burkina Faso	330 (745)	248 (505)	1126 (750)	256 (391)	1961 (640)	195 (394)	1180 (323)	3336 (472)	9255 (148)	1099 (175)	293 (141)	2955 (407)	14,300 (183)	17,635 (213)
Ethiopia	264 (340)	13 (434)	895 (112)	556 (290)	1728 (176)	147 (279)	3581 (126)	5456 (142)	26,377 (129)	3750 (218)	2141 (90)	9998 (294)	44,561 (160)	50,017 (158)
India	19,339 (837)	940 (94)	940 (94)	2926 (216)	28,175 (387)	8112 (189)	161,329 (80)	197,698 (102)	251,993 (44)	11,825 (81)	69,346 (99)	589,146 (315)	1,006,559 (153)	1,204,175 (143)
Kenya	166 (589)	72 (360)	1373 (204)	263 (204)	1874 (224)	222 (273)	6037 (85)	8133 (108)	13,780 (181)	1314 (154)	4626 (127)	15,045 (254)	37,830 (197)	45,963 (176)
Nicaragua	160 (129)	15 (79)	54 (95)	0 (–)	229 (117)	31 (55)	568 (27)	829 (44)	1012 (30)	174 (64)	95 (27)	423 (80)	2164 (50)	2992 (48)
Tanzania	494 (607)	99 (452)	1423 (328)	293 (472)	2310 (390)	172 (334)	5669 (236)	8152 (271)	12,265 (152)	3064 (195)	18,160 (139)	21,401 (329)	58,551 (200)	66,702 (207)
Uganda	506 (701)	631 (407)	907 (510)	302 (548)	2346 (512)	110 (420)	4583 (280)	7039 (337)	7047 (211)	2443 (255)	18,336 (180)	26,207 (289)	57,070 (236)	64,109 (245)
Vietnam	1383 (152)	4601 (78)	579 (103)	31 (184)	6595 (93)	561 (160)	1842 (82)	8999 (94)	16,619 (15)	953 (49)	1744 (22)	20,906 (57)	44,115 (38)	53,113, (45)
Aggregate	22,644 (670)	6619 (102)	11,328 (176)	4628 (252)	45,219 (144)	9550 (195)	184,789 (87)	239,559 (110)	338,347 (56)	24,621 (122)	114,740 (113)	686,081 (293)	1,265,150 (151)	1,504,708 (144)

[a] All demand given in '000 Mton in 2050, and percent (%) change compared to 2010 in brackets (Source: Authors' calculations from FAO statistics and IMPACT results).
[b] All meat includes poultry, cattle, sheep and goat, and pig Meat.
[c] All LDF includes all meat, milk and eggs. (Source: author's calculations from IMPACT results).

Table 4
Projections of change in demand for selected food categories in 2050, under alternative scenarios of economic or climatic change[a].

		Eggs	Milk	Pork	Beef	Lamb	Poultry	All LDF	All CDF	ALL food
Burkina Faso	High economic growth	0.06	0.03	0.15	0.25	0.04	0.23	0.13	(0.07)	(0.03)
	Low economic growth	(0.07)	(0.03)	(0.15)	(0.23)	(0.05)	(0.22)	(0.13)	0.10	0.05
	Climate change	(0.01)	(0.01)	(0.02)	(0.01)	(0.00)	(0.02)	(0.01)	(0.05)	(0.04)
Ethiopia	High economic growth	0.08	(0.07)	0.24	(0.10)	0.07	0.11	(0.04)	0.01	0.00
	Low economic growth	(0.06)	0.10	(0.17)	0.15	(0.06)	(0.08)	0.08	0.02	0.03
	Climate change	(0.01)	(0.01)	(0.02)	(0.01)	(0.00)	(0.02)	(0.01)	(0.04)	(0.03)
India	High economic growth	0.07	(0.04)	(0.03)	(0.03)	0.06	0.36	0.01	0.08	0.07
	Low economic growth	(0.09)	0.04	0.05	0.04	(0.08)	(0.33)	0.00	(0.08)	(0.07)
	Climate change	(0.00)	(0.00)	(0.02)	(0.01)	(0.00)	(0.01)	(0.01)	(0.04)	(0.03)
Kenya	High economic growth	0.11	(0.10)	0.22	0.03	0.01	0.33	(0.06)	0.07	0.04
	Low economic growth	(0.02)	0.25	(0.10)	0.08	0.08	(0.18)	0.20	0.03	0.06
	Climate change	(0.01)	(0.00)	(0.02)	(0.01)	(0.00)	(0.02)	(0.01)	(0.06)	(0.05)
Nicaragua	High economic growth	(0.08)	(0.11)	(0.05)	(0.04)	(0.04)	(0.03)	(0.09)	(0.07)	(0.07)
	Low economic growth	0.25	0.31	0.21	0.17	0.16	0.16	0.27	0.23	0.24
	Climate change	(0.01)	0.00	(0.02)	(0.00)	0.00	(0.02)	(0.00)	(0.04)	(0.03)
Tanzania	High economic growth	0.00	(0.06)	0.09	(0.02)	0.06	0.13	(0.03)	(0.07)	(0.06)
	Low economic growth	(0.01)	0.05	(0.08)	0.02	(0.07)	(0.11)	0.03	0.06	0.05
	Climate change	(0.01)	(0.00)	(0.02)	(0.01)	(0.00)	(0.02)	(0.01)	(0.05)	(0.04)
Uganda	High economic growth	(0.01)	(0.08)	0.00	0.04	0.04	0.11	(0.04)	(0.10)	(0.10)
	Low Economic Growth	(0.00)	0.09	(0.01)	(0.04)	(0.06)	(0.11)	0.04	0.11	0.10
	Climate change	(0.01)	(0.00)	(0.02)	(0.01)	(0.00)	(0.02)	(0.01)	(0.03)	(0.03)
Vietnam	High economic growth	0.08	0.03	0.02	0.04	0.08	0.08	0.04	(0.01)	(0.00)
	Low economic growth	(0.05)	0.00	0.00	(0.01)	(0.06)	(0.05)	(0.01)	0.04	0.03
	Climate change	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)	(0.05)	(0.04)

[a] Estimates are percentage (1.0 = 100%) changes relative to the reference scenario of moderate economic growth (see Table 3 for level estimates of the reference scenario). Negative changes are in parenthesis. (Source: author's calculations from IMPACT results).

3.2. Assessing household level production and consumption of LDF

The IMPACT scenario outcomes are national averages, making it necessary to look to other data to infer implications of the dietary transitions for target segments of the population, such as poor farming households. Our approach is to assess the current role of less wealthy strata in the livestock sector, as an initial indication of the future, the thinking behind this being that it is probably easier to enhance the involvement of smallholders already engaged in the sector, than to move new groups of the less affluent into an often capital and knowledge intensive sector. Data from the DHS program (Rutstein and Rojas, 2006) were used in this paper to assess livestock ownership and consumption of livestock products at household level, to identify opportunities for livelihood and nutrition benefits.

The DHS program is focused on young children and women of reproductive age and has since 1984 carried out more than 130 nationally representative household-based standard surveys in more than 70 countries. The DHS surveys primarily produce data on human health and nutrition for different wealth categories, but include, in addition, information on household assets and consumption patterns. We examined country-wide data on livestock-ownership patterns and LDF consumption among children differentiated for the five available

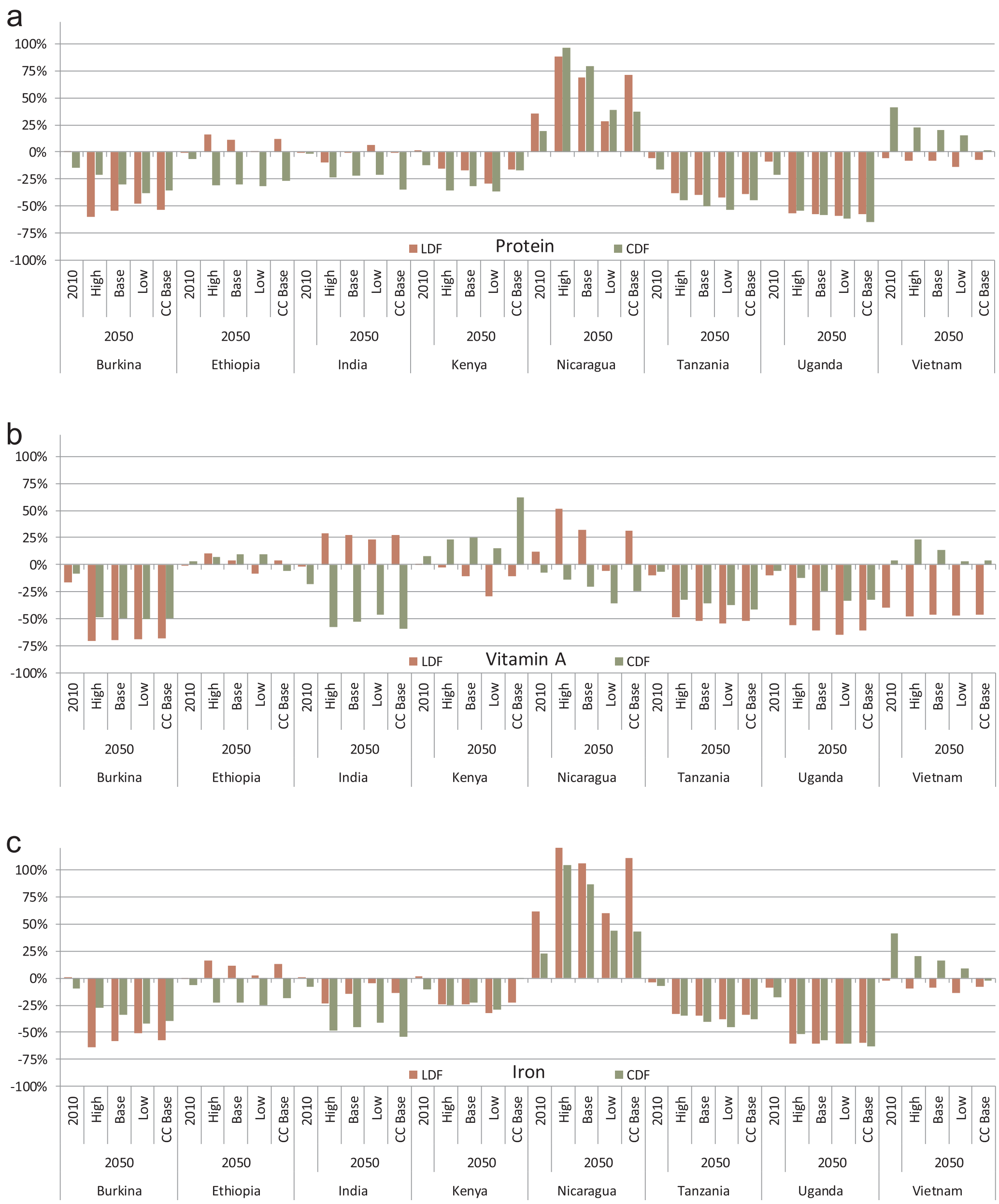

Fig. 1. Net trade in percentage relative national demand of crop- and livestock-derived foods of a) protein, b) vitamin A, and c) iron for 2010 and four scenarios of 2050 (Source: authors' calculations from IMPACT results).

household wealth categories, here denoted, poorest, poor, medium, rich and richest. The data was computed using appropriate sample weights to correct for possible oversampling in areas with low population densities.

Ownership of cattle, goat, sheep, pigs, and poultry, were assessed to observe the extents to which smallholders already are part of national livestock production. Existence of less affluent livestock producers gives an indication of chances for short-term interventions to reach, retain and further increase the engagement of these groups in national livestock production, and potential nutritional benefits that could accrue from such interventions. Data on the consumption of LDF by children under the age of five, obtained from recall data on food items mothers provided to their last-born child aged between 1 and 5 years in the 24-h period prior to the interview, was used to assess the rates at which mothers in livestock-owning households fed LDF to their children, compared to those in households that do not own livestock. Our analysis however did not assess other types of sub-national heterogeneity in LDF consumption such as can be imposed by geographical location.

DHS standard surveys were analyzed for the four study countries for which DHS *recode V* data were available, i.e. Burkina Faso (INSD/ICF, 2012), Ethiopia (CSA/ICF, 2012), Kenya (KNBS/ICF, 2010), Uganda (UBOS/Macro, 2007) and Tanzania (MoHCDGEC/MOH/NBS/OCGS/ICF, 2016). Additional years of relevant data made it possible to assess change over time in Kenya (KNBS/ICF, 2014), Uganda (UBOS/ICF, 2012) and Ethiopia (CSA/ICF, 2016).

4. Contributions of LDF to future food nutrient supplies

Our discussion of the economic model projections covers simulated changes (between 2010 and 2050) in the demand, production and trade of LDF under the reference and alternative scenarios of economic growth and climate change. Associated contributions of LDF to food nutrient supplies of the countries are discussed. Inferences are then presented from the analysis of household survey data for how LDF will potentially contribute to the livelihoods and nutrition of smallholder families.

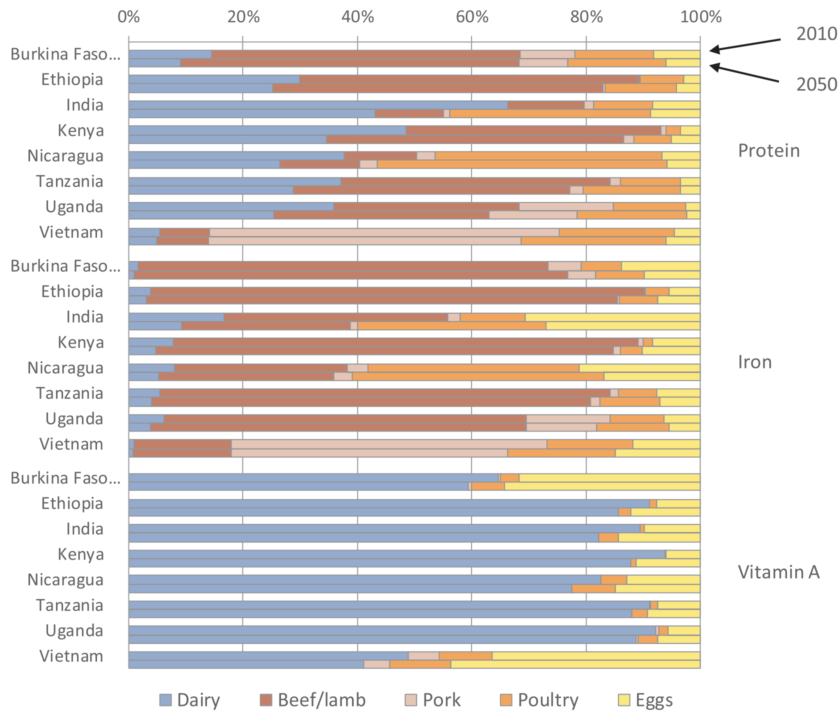

Fig. 2. Percentage contribution of different LDF types to per capita supplies of LDF nutrients, comparing 2050 (upper bar), medium growth scenario, and 2010 (lower bar), baseline situation (Source: authors' calculations from IMPACT results).

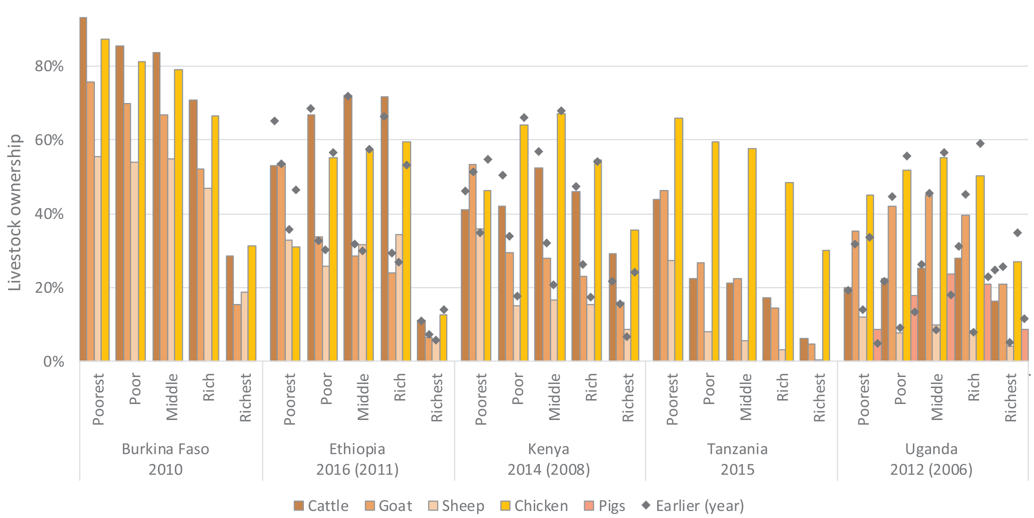

Fig. 3. Shares (%) of households that keep livestock in selected countries, by wealth categories. For most recent year(s) for which data is available. (Source: DHS data).

4.1. Projections of food supplies in 2050

Under the reference scenario of moderate growth between 2010 and 2050, the aggregate national demand for LDF increased in all eight countries, by 44% in Nicaragua, between 94% and 142% in Vietnam, India, Kenya and Ethiopia, and by 200%, or more, in Burkina Faso, Tanzania and Uganda. In comparison, the demand for CDF increased by less than 50% in Nicaragua and Vietnam, and between 153% and 236% in the other six countries. The demand for LDF increased more relative to the demand for CDF in half of the study countries, i.e., Burkina Faso, Tanzania, Uganda and Vietnam; with CDF demand growth stronger in the other four (Table 3). Increase in CDF demand was strongest for fruits and vegetables (between 57% and 407%). Fruits and vegetables also showed the strongest demand growth overall. Increase in the demand for LDF was strongest for poultry meat, with more than 700% change between 2010 and 2050 in Burkina Faso, India, and Uganda.

Projections showing that LDF demand was surpassed by demand growth of CDF in Nicaragua, India, Kenya and Ethiopia, agree with the narrative that rising per capita incomes in lower income countries will lead to increased diversification of diets (Delgado et al., 2001), but the results for these countries identify a fruits and vegetables "revolution", rather than a livestock one. In Kenya and India, LDF consumption (of milk in particular) could be considered high compared to many other LMICs, while in Nicaragua a contributing factor to the slowing pace of LDF demand growth could be that per capita consumption already increased substantially over the decades prior to 2010 (FAO, 2015), leaving narrower scope for further increases. In the case of Ethiopia, demand responses for LDF have been shown to be similar in rural and urban areas (Tafere et al., 2010), while cultural/religious dietary practices restrict consumption of LDF on many days in the year. These

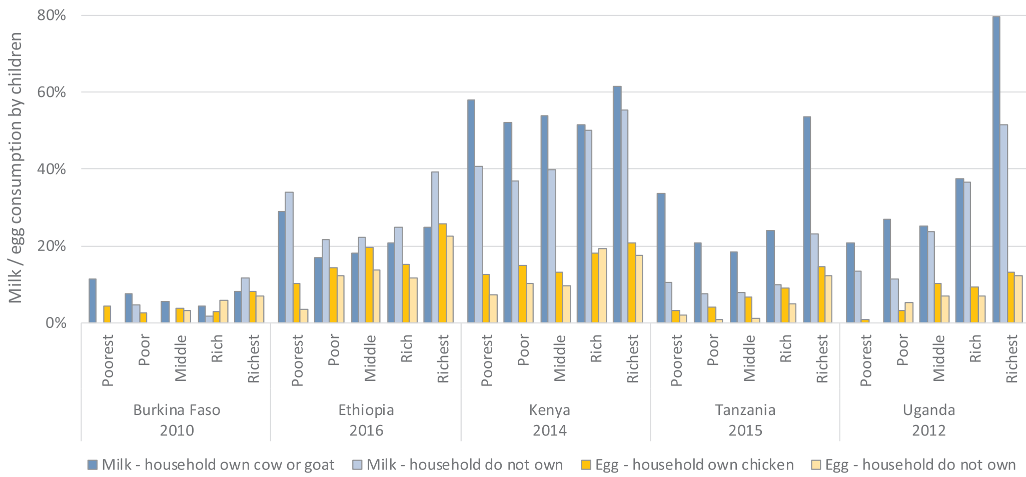

Fig. 4. Shares (%) of households that fed (in last 24 h) milk/eggs to last-born child aged 1–5 year, among families that own/do not own cows and goats (milk) and chicken (eggs), in the Study Countries and DHS survey years, by wealth categories (Source: DHS data).

factors indicate more limited potential for the type of dietary transformation observed elsewhere.

World bank statistics (2016) show that the countries for which our model simulations indicated higher demand increases for LDF relative to CDF in 2050, i.e., Burkina Faso, Tanzania, Uganda and Vietnam, all managed to achieve relatively high levels of economic growth (6% or more on average annually) over the last twenty years. Compared to the global average of 25.4 g per person per day, supply of LDF (in protein terms) was relatively low in three of these countries in 2010: Burkina Faso, Tanzania and Uganda at 41%, 30% and 35%, respectively, of the global average (FAO, 2015), providing considerable scope to expand demand and supply. In addition, projections on growth rate of urbanization are quite high for all four countries, at 2% or more annually (Table 1). While expectations on urbanization are accounted for only implicitly in IMPACT, they likely explain in part the model's projections of increases in LDF demand.

There was substantial variation in how aggregate food production in the study countries translate to net national supply of LDF and CDF, both by country and across commodities. Four countries had aggregate net food export positions in 2050, namely Ethiopia, Nicaragua, Uganda and Vietnam, while the other four were net food importers. In the case of LDF only, four countries were net exporters with Ethiopia exporting milk and meat from cattle, sheep and goats, and India and Kenya exporting milk. Nicaragua showed substantial net export of all types of LDF products. The net LDF-importing countries showed heavy import dependence, corroborating findings from earlier studies (Herrero et al., 2014). The volume of imports was estimated at around half the domestic LDF demand in Burkina Faso, Tanzania and Uganda, and about one fifth in Vietnam. These results could highlight increased needs for functioning cross-border food trade systems in the future, and lead to interesting trends in the supply of macro and micro nutrients.

4.1.1. Food supplies under alternative scenarios

Compared to the moderate growth scenario, projections of demand for both LDF and CDF commodities were typically higher under the high growth scenario and lower under the low growth one. Demand under the climate change scenario was typically lower than the high growth scenario, but higher than demand in the low growth scenario. Table 4 presents scenario-related differences in countries' demand for different LDF types and in aggregate in 2050. For most of the countries, differences in the estimates of demand were observed to be quite large between the high growth and low growth scenarios (with the climate change case in-between). In India for example, poultry demand under the high growth scenario was as much as 36% higher than the estimate of demand under the reference scenario, while demand under the low growth scenario was 33% lower. In Burkina Faso, volume of beef demand under the high and low growth scenarios differed by up to 48% points. Such observations could mean that livestock sector interventions that rely on correctly gauging future demand and supply of LDF, e.g., those focused on the marketing and retail of LDF products, will be less appropriate.

Also of interest, is that food demand estimates under climate change were lower than under the high growth scenario, but not lower than those under low growth, suggesting reduced impacts from climate change relative to adverse economic conditions. However, it is important to note that the partial equilibrium framework of the model used did not explicitly link production or market outcomes back to consumer demand, underestimating the impacts of production-side shocks on household consumption. Specifically, the food consumption decisions are not as strongly linked to household production outcomes as will generally be observed in many low-income countries where farming families consume a large portion of their own produce (Hoddinott et al., 2015). Further, similar to Havlik et al. (2015), assumptions on free flow of goods across borders potentially over-amplify the potential for overcoming gaps in national demand for LDF that would otherwise be exacerbated under climate change. In reality, as countries face political unrest from food system disruptions, including from bad weather, as witnessed in the global food crises of the mid-to late 2000s (McDermott et al., 2013; Rosegrant et al., 2013); net-producing countries could close their borders as precautionary measures, making access to food more difficult for the more food import-dependent nations. Importing countries also necessarily need to be concerned about open borders in relation to livestock disease outbreaks (McDermott et al., 2013).

4.1.2. Nutrient profiles of LDF supply projections

Implications of food demand, production and trade for the supply of three essential nutrients for all four analyzed future scenarios are illustrated (Fig. 1). Burkina Faso, Tanzania and Uganda imported at least 40% of their supply of livestock-derived protein under all scenarios, while Ethiopia and India were mostly net exporters of LDF proteins. Both Ethiopia and India imported CDF proteins. Vietnam showed the opposite pattern, exporting CDF proteins while importing LDF proteins. Only Nicaragua produced a major surplus of both LDF and CDF proteins. The general inference is that by producing surplus of other food groups, countries potentially mitigate risks of insufficiency in nutrient supplies brought about by low production of any major food groups. Dietary diversity does certainly contribute to nutrient adequacy

(Martin-Prevel et al., 2009), but ready substitution of nutrients regardless of source may not always be possible (USDA and USDHS, 2010). In heavily import-dependent Burkina Faso and Tanzania, there was limited scope for even such substitution.

Across the study countries, the different LDF types together accounted in 2010 for between 7% and 18% of per capita food supplies in kilocalorie terms but, thanks to their nutrient profile, between 9% and 26% of dietary proteins, and between 2% and 48% of Vitamin A supplies (i.e., nearly half in Nicaragua). LDF in addition supplied between 2% and 5% of dietary iron. As the essential amino-acid profile of animal proteins might be better suited for adequate child growth than proteins from most plant sources (USDA and USDHS, 2010), while Vitamin A is key for body immune function (Black et al., 2013), this is an important result. In addition, although iron may be higher from plant sources (e.g., beans), iron in LDF tend to be more easily absorbable. LDF products contributed differently to the overall nutrient profiles of the study countries (Fig. 2). In 2010, dairy provided the highest supply of protein in India (66%), Kenya (49%) and Uganda (36%) while beef and small ruminant (sheep and goat) meat provided more than half of the LDF proteins in Ethiopia, Burkina Faso, Tanzania, and Kenya. Pig meat similarly provided more than half of the LDF proteins (61%) in Vietnam, and 16% in Uganda. These statistics reflect the content of these nutrients in the specific LDF products, e.g., milk and eggs account for a major share of vitamin A from LDF supplies, as well as the importance of different livestock types in the countries, e.g., cattle, sheep and goats in Burkina Faso, poultry in Nicaragua, and pigs in Vietnam. However, a visible trend when comparing nutrient profiles of the various countries' LDF supplies (e.g., under the reference scenario), is that the importance of dairy and beef/lamb generally decline in 2050, while that of poultry meat and eggs increased. This is important for anticipating the role of livestock production in the future, including for smallholder farming families.

4.2. Livestock production and LDF nutrient supply at household level

In Burkina Faso, Tanzania and Uganda, LDF demand growth increased quite substantially from 2010 to 2050. In the same countries, DHS household-level data revealed high rates of livestock ownership among the rural population. Nearly 80% of all households in Burkina Faso owned livestock in 2010, as well as 57% of households in Tanzania in 2015 and 62% (59%) in Uganda in 2006 (2012). Estimates of livestock ownership were also quite high in Kenya and Ethiopia, at more than 60% in the most recent years for which data is available. In Burkina Faso and Tanzania, ownership of the different types of livestock was most prevalent amongst the poorest households (Fig. 3). According to the surveys, livestock ownership was not concentrated amongst the richest quintile in any of the countries. Cattle ownership was the most common form of livestock-keeping in Burkina Faso and Ethiopia, while more households kept poultry in Kenya and Uganda. Pig ownership was only recorded in Uganda. Assessing these statistics against the model projections of 2050, it is observed that future LDF demand growth is quite strong for LDF products that smallholder farmers already produce.

Although the data and analysis did not allow for direct assessment of whether or not smallholder producers can participate in the livestock production of the future, they help identify, through a scoping of the current status on ownership of livestock, the potential for such participation. By showing that a large segment of less affluent producers in Burkina Faso, Tanzania, Ethiopia and Uganda are already engaged in livestock production, the nationally representative data point to the potential for targeting instruments for pro-poor livestock-sector development in these countries. The patterns of livestock ownership in the countries likely reveal traditional roles of livestock among rural populations (Herrero et al., 2013), while dynamics in Uganda, at least in the case of poultry, likely show the influences of a major donor-funded intervention (Dessie and Getachew, 2016). This example of sustained participation of the poorest households in livestock production points to opportunities for improved household nutrition and livelihood outcomes.

The consumption data showed that for the poorest households, the rates of mothers feeding milk to their last-born child aged between one and five were higher for those living in households that owned a cow or a goat (Fig. 4). In the rich and richest households, higher rates of egg consumption were found for children living in households that owned chickens. Generally (i.e., except in Ethiopia), cattle, goat and chicken ownership among the poorest increased the rates of LDF consumption by children, compared to households that did not own livestock. The observation that consumption of LDF by young children increased for those living in households that keep livestock animals was clearer for households that owned dairy animals and egg-laying chickens, and to a lesser degree, households that kept poultry animals for meat, a finding consistent with earlier studies (Kryger et al., 2010). Although additional analysis is needed, an informed posit is that large-scale investments to aid ownership of livestock animals could improve access of children in poor households to high-value food nutrients in up to three of the study countries, and that this holds for both dairy and poultry.

5. Research, investment and policy considerations

This paper presents forward-looking analyses of the contribution of LDF to human diets in Burkina Faso, Ethiopia, India, Kenya, Nicaragua, Tanzania, Uganda and Vietnam - eight countries relevant to pro-poor livestock sector development. A growing need to identify broad-based intervention options for the livestock sector that meet multiple objectives for food security, livelihoods and nutrition, within the context of rapidly changing demand for livestock products, motivated the study. Results show that supply of LDF grows substantially and relative to other food groups in at least four of the countries. Under alternative scenarios of economic or environmental change, up to four of the study countries are found to be heavily dependent on LDF imports in 2050, underscoring motivation to improve the current productivity and production of LDF in these countries, or improve cross-border livestock markets and food distribution networks. Projections of the future demand for LDFs in countries such as Burkina Faso and Tanzania, are however highly variable, with implications for policy. These countries may need to approach market-based programs and policies for livestock sector development more cautiously. For one, the current state of infrastructure (e.g., lack of cold chains) likely limit market-focused strategies. These countries could focus instead on intervention options that increase livestock productivity, e.g., through reducing the unit costs of production, and strategies that better channel nutritional benefits to target populations.

Household level data reviewed alongside the scenario analyses revealed incentives for promoting smallholder involvement in future production of livestock, showing that countries in the study may find it useful to boost investments in local production to meet future demand for LDF and nutrients, take advantage of livelihood opportunities for smallholder producers of livestock, and improve the nutrition of poorer populations. Our assessment of time-varied data may have picked up on effects of a large-scale intervention to improve poultry ownership in Uganda, and by extension improvements in the diets of children in poor households. However, more robust data and analysis is needed to better establish these links, and to contribute to current debate on how livestock asset endowments match up against other interventions, including cash transfers to the poor. Although nationally-representative household-level data have been helpful for assessing the links between livestock ownership and aspects of human diets, there was not sufficient historical data for more conclusive arguments. Dairy and poultry production offered the highest potential for channeling livelihood benefits and key food nutrient supplies to the poor, but specific interventions, including possibly, those that go beyond the sector (e.g., education, sanitation), will need to be more rigorously assessed to better quantify livestock's future role in the food security of LMICs.

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Declarations of interest

The authors declare that there are no conflicts of interest.

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