Developing and testing improved analytical tools for priority setting of livestock research

ILRI PROJECT REPORT

Developing and testing improved analytical tools for priority setting of livestock research

Dolapo Enahoro[1], Catherine Pfeifer[1], Aymen Frija[2], An Notenbaert[3], Karl Rich[1], Stephen Oloo[1] and Nils Teufel[1]

[1]International Livestock Research Institute

[2]International Center for Agricultural Research in the Dry Areas

[3]International Center for Tropical Agriculture

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Box 30709, Nairobi 00100 Kenya
Phone +254 20 422 3000
Fax +254 20 422 3001
Email ilri-kenya@cgiar.org

ilri.org
better lives through livestock

ILRI is a CGIAR research centre

Box 5689, Addis Ababa, Ethiopia
Phone +251 11 617 2000
Fax +251 11 667 6923
Email ilri-ethiopia@cgiar.org

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Abbreviations and acronyms

CGE	Computable General Equilibrium
CLEANED	Comprehensive Livestock and Aquaculture Environmental Assessment for Improved Nutrition, a Secured Environment and Sustainable Development along Value Chains
CRP	CGIAR Research Program
ES	economic sector
GDP	gross domestic product
GDPPC	gross domestic product per capita
IDOs	intermediate development goals
IFPRI	International Food Policy Research Institute
ILRI	International Livestock Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IP	impact pathway
LDF	livestock-derived foods
LMIC	low- and middle-income countries
PAC	priority assessment criteria
PE	partial equilibrium
PIM	Policies, Institutions and Markets
R&D	research and development
SLOs	system level outcomes
TOC	theory of change

Disclaimer

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1. Introduction

A quantitative assessment tool, previously developed for the prioritization of livestock research at the International Livestock Research Institute (ILRI), was adapted for use in the phase II proposals of the CGIAR research program (CRP) on Livestock agri-food systems (McCleod 2016). However, some identified weaknesses limit the potential of this tool to contribute to a wider scope of ex-ante impact assessments. These weaknesses include limitations in the selection and calculation of indicators used to assess the potential socioeconomic and environmental outcomes of candidate research options and a weak accounting for appropriate research impact pathways within the prioritization framework. Thus, an activity was proposed to develop a new prioritization framework using improved analytical models and data sets. The aim of this exercise was to enhance the ability of the Livestock CRP to prioritize research investments. The new prioritization framework generated from this exercise contributes data, tools and methods that will guide the evolution of the program's research portfolio towards improved alignment to universal goals of poverty reduction, food and nutrition security and enhanced management of natural resources. Amongst other outcomes, a better-aligned research portfolio of the Livestock CRP will contribute value through generating research outputs that develop and deploy improved agronomic and animal husbandry practices, contribute to reduced market barriers for target producers, provide improved livelihood opportunities for poorer livestock-keeping households and improve access to healthier diets for nutritionally vulnerable populations. The proposed analytical framework incorporates quantifiable measures of important research impacts, potentially providing more credible estimates for CRP outcome targets.

This report summarizes the motivation, methods and results from this exercise to upgrade the existing framework and tools for livestock research prioritization under the Livestock CRP. The next section presents a review of previous prioritization exercises on agricultural research within the CGIAR and livestock research at ILRI under the Livestock CRP. The concepts, tools and data informing these exercises are also presented. Then, a section follows describing proposed extensions to the existing analytical framework, which first outlines identified gaps. Next, we present the outcomes from developing and testing improved tools within this framework. We present the underlying data and analysis. The final section summarizes the implications of the current exercise and concludes on the way forward.

2. Prioritization of international agricultural research

Setting priority to determine the allocation or reallocation of research funding takes many different forms (Thornton et al. 2000). These include informal or ad hoc ranking of research priorities, the use of previous years' funding as indicators of the relevance of a current portfolio and the allocation of resources (e.g. public sector) based on the proportional contribution of underlying themes to some envisaged total value (e.g. agricultural production). More rigorous approaches include: (i) peer reviewed processes in which subject and region experts provide feedback on the value of candidate technological interventions that is systematically organized to inform decision-making (Vercoe et al. 1997; Kristjanson et al. 2009; Reece et al. 2004); (ii) economic cost-benefit and economic surplus modelling (Alston et al. 2011; You and Johnson 2010; Briones et al. 2008); and (iii) scoring methods that link data on technological changes in agriculture to previous investments (Allen et al. 2014). These approaches have been adopted across CGIAR to prioritize agriculture and food systems research and livestock-specific research within ILRI and livestock-focused CGIAR research programs. An increasingly important focus at all levels has been to emphasize the developmental aspects of research for development, with attempts made to better link research funding to activities that promote realization of agreed goals of global development, such as poverty reduction, improved nutrition and employment generation. For example, some early studies prioritized investments in the management of livestock diseases based primarily on their impacts on the poor (Perry and Grace 2009).

2.1 Agricultural research prioritization

Norton and Raitzer (2009) laid out several key principles for improving the process of setting priority for research, focusing on experiences garnered from CGIAR centres over two decades. At least two of these principles are of immediate relevance to livestock research. First, the tools and methods underlying the analysis need to be well established. Second, growing demands on research in the form of internationally agreed development objectives need to be better addressed. Other areas were highlighted as important to improve, including (1) the measurement of the contributions of different research investment options to stated objectives, (2) better factoring in of the primary concerns of key decision makers and (3) involvement of the final decision makers in the analytical process. Norton and Raitzer (2009) further enumerate central features of research prioritization, i.e. that it meets its primary objectives including the utilization of credible theories, processes and analytical methods, and the devoting of adequate resources to improving measures of difficult-to-quantify research contributions, such as those attributable to natural resources management.

Furthermore, a successful exercise in setting priority in research clearly identifies the key decision-makers and what decisions need to be made. This approach clearly defines alternatives to be prioritized, as well as the specific objectives to be pursued, and adequately measures the proportional contributions of research programs to the stated objectives. Good data and analysis are typically needed for all of these objectives. While income or welfare impacts have been measured with some degree of consistency and rigour in the previous analyses, measures such as environmental and health impacts have not been so well captured. Additional investments are thus needed to obtain the needed data, whether from primary or secondary sources, or expert knowledge. Better accounting for donor or decision-maker perspective in the analysis may also be key to successful research prioritization. Results from these quantitative analyses should be shared with the appropriate decision-makers in an iterative manner in order to get sufficient feedback from end users into the full process of priority setting. At the same time, data and methods used for assessments of research impacts remain more easily within the influence of researchers than, for example, donor responses.

A recent study led by the International Food Policy Research Institute (IFPRI), used an integrated assessment model of the global agriculture and food system to quantify the impacts of alternative investment options on system level outcomes (SLOs) of the CGIAR (Rosegrant et al. 2017). The study provided information and evidence on the impact of joint CGIAR efforts in agricultural research and development (R&D), as well as the role of complementary investments. The study complemented other efforts to assess the overall impact and benefits of investing in international and national agricultural research programs in relating plausible changes in population, income, technology and climate to 2050 to indicators of poverty (SLO1), food and nutrition security (SLO2) and natural resources and ecosystem services (SLO3). Studies such as this apply updated data and analytical tools to agricultural research prioritization, while incorporating pre-identified end user expectations (SLOs in this case) in the assessment of outcomes. The exercise did not set out to prioritize between different possible research themes and thus did not set out specific prescriptions for future investments in international agricultural (and livestock) research. A more recent exercise led by IFPRI incorporated elements of research prioritization but did not include livestock in the assessments (Multi-Funder Group 2018) (see annex 2).

Additional analysis of the model outputs presented in Rosegrant et al. (2017) showed that R&D interventions to improve the productivity of livestock production better served strategies to improve food security and producer incomes in South Asia and sub-Saharan Africa. For instance, Enahoro et al. (2019) showed that competing investments in market-enhancing interventions improved benefits to consumers but led to greater threat of negative environmental impacts.

2.2 Setting priority for livestock research

To maintain both rigour and practicality, setting priority for international livestock research at ILRI has favoured the use of a mix of economic benefit-cost approaches, scoring methods and weighted indices (Thornton et al. 2000; Randolph et al. 2001; McCleod 2016). One of the earlier attempts combined scoring and peer review methods (ILRI 1996). Four criteria were used within this exercise to determine the relative importance of different research themes targeted to enhance development outcomes. These were: (i) potential economic and environmental benefits; (ii) the ability of target beneficiaries to exploit research results; (iii) time frame of the research phase and probability of success; and (iv) ILRI's capabilities and comparative advantages in the specific area(s) of research.

An assessment framework was further developed by this process in 1999, under the Priority Assessment Criteria (PAC) working group of the institute (Thornton et al. 2000). The assessment of the PAC working group involved more than one hundred scientists from ILRI and partner organizations in a participatory process to elicit and organize expert knowledge on the value of different research streams. Candidate research themes were selected based on questions related to the scale of importance of livestock sector challenges and the goals and expected benefits of proposed work in terms of anticipated contributions to poverty reduction, food security and improved environmental management. Also important for candidate research themes were the researchability of presented issues, probability of research success, ILRI's complementary and comparative advantage as lead research institute and notional resource requirements. Results from this priority-setting exercise indicated that the activities underlying the suite of research themes at that time will have led to a wide range of impact, with no themes scoring highly in all criteria. As such, a portfolio approach was recommended that allowed to pay attention to inevitable trade-offs.

Thornton et al. (2000) assessed five specific criteria for candidate research options: (i) economic impacts; (ii) poverty reduction; (iii) environmental impacts; (iv) internationality of the problem(s) and solution(s); and (v) contribution of the research activity to capacity development within the target countries (see Table 1). Economic returns received high weighting in the overall prioritization. Expected economic impact was estimated using an economic surplus model applied to a closed economy (Alston et al. 1995). The size of the gain to typical users in the different agro-production systems, number of users realizing the gain and the likelihood of successful innovation all determined the magnitude of economic benefits. On the cost side, direct expenses to produce research stream products and services, financing for adaptive research and other public funding needed to deliver research to its final users were factored. A calculated benefit-cost ratio defined expected dollar returns for each dollar of research investment. Results of the benefit-cost analyses were then related to indices of poverty to determine their poverty reduction potential, with research streams having large economic benefits in livestock systems with higher numbers of poor people and/or greater inequality adjudged to have higher poverty impacts. Research streams were scored for direct environmental impact on soil and water resources, greenhouse emissions and biodiversity, although these impacts were not explicitly quantified. The Simpson's diversity index, which will give greater weight to activities that raise producer and consumer welfare in more countries of the world, was used to measure the internationality of the solutions offered by candidate research. Finally, a capacity development framework was employed that scored research streams as low, medium or high depending on their potential to enhance individual and institutional capacity of partner research and other organizations.

Key suggestions following the assessments included the need to improve on the identification of recommendation domains that are the basis for determining the extent of the problem and potential solutions. The need for better data on production, human welfare and other key intervention impacts are also emphasized. To factor into the quantitative analysis the fact that some variables influencing the measurement of impacts are inherently uncertain, Randolph et al. (2001) introduced the use of Monte Carlo techniques, simulating the uncertainty surrounding key discrete variables. Results from this follow-on exercise showed high variability in potential impacts of component research activities, further confirming the importance of a portfolio approach and possibly, relevance of such an approach in the prioritization of global research investments. Beyond immediate uses of the results, the priority-setting exercise carried out by the PAC working group made important methodological contributions in two areas: providing guidelines for improving on the performance of impact indicators in ex-ante impact analysis and demonstrating the usefulness to set research priority on sensitivity analysis and outcomes probability modelling. However, questions of whether specific sequencing of the components of a portfolio approach are needed to manage trade-offs were not addressed.

In a recent application, McCleod (2016) used the priority-setting framework developed by Thornton et al. (2000) and Randolph et al. (2001) to evaluate the comparative advantage, opportunities offered and expected impact of research streams proposed for the Livestock Agri-food CRP (ILRI et al. 2016). This prioritization exercise for the second phase of the CRPs maintained the combined scoring and economic benefit-cost approaches of the earlier framework, while expanding the measurement of impact to include a sixth criterion—inclusiveness (see Table 1). The inclusiveness criterion reflects the CGIAR-wide growing attention to effects of CGIAR's global research on assets, income and equity issues related to gender and youth. The exercise found substantial variability in the relative contribution of each criterion to the composite index. Each of five proposed CRP flagships contained at least one highly ranked research stream. Overall, the portfolio showed a balanced mix of higher and lower risk investments, recording a high benefit-cost ratio of 9:1 and thus seeming to offer good economic returns to new investments. However, there remains a challenge to ensure that other objectives of the final decision-maker are correctly factored into the formal analytical process. Not all five research flagships informed using the prioritization framework were considered suitable for funding by the external review council. This could reveal, at least in part, misalignment between the analytical process and criteria relevant to the final decision-maker. Improving the match of proposed research with the objectives of key decision-makers may need to be better reflected in internal priority setting, and this may become more important as public funding for international agricultural research and development is undergoing rapid changes (Pardey et al. 2015).

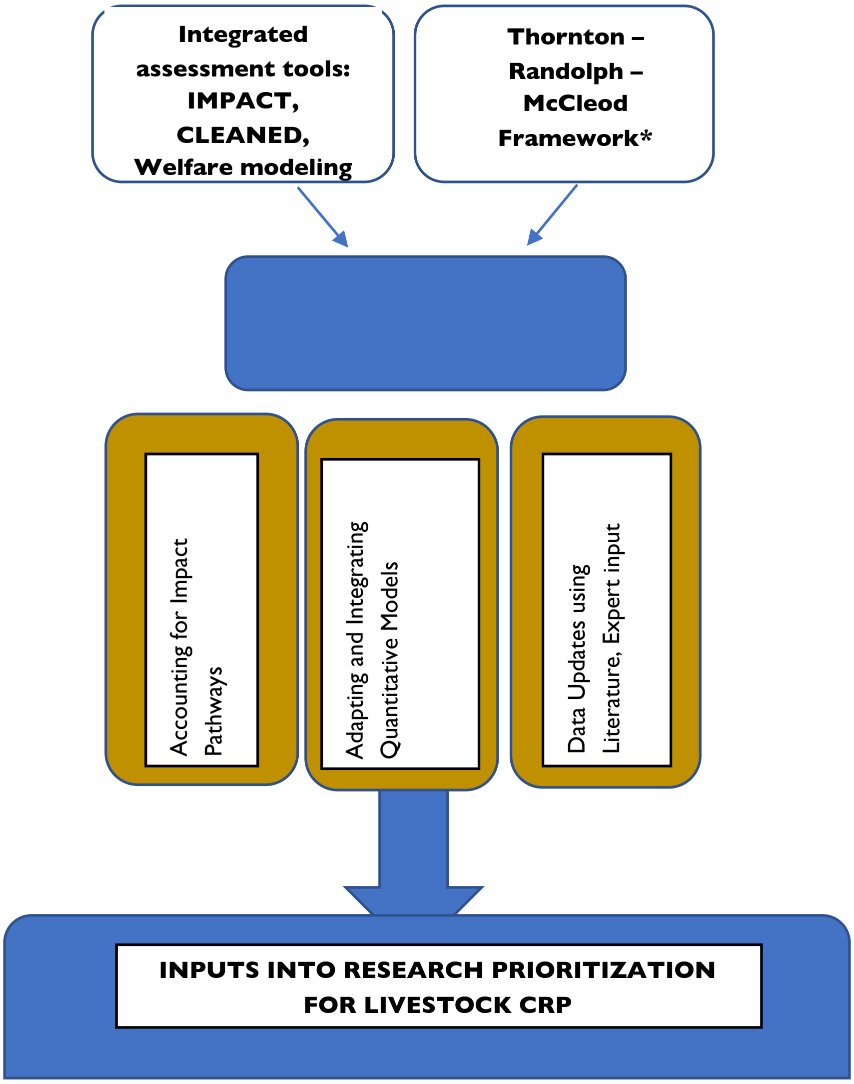
Ten years after, a 2009 study assessed lessons learned from applying the analytical framework earlier developed at ILRI for setting priority of international livestock research (Kristjanson et al. 2009). That study showed the ranking of ILRI's livestock research themes (26 at the time) generally matched scientist expectations. These outcomes had been incorporated into the institute's research planning over the next six or seven years leading to, amongst other outcomes, an emphasizing of research on poverty mapping[1] ; a de-emphasizing of pastoral system issues ;[2] and in terms of institutional structure, the spread across other programs of the institute's research then under the policy and capacity building research themes .[3]

3. Suggested improvements to the analytical frameworks and tools

Some gaps were noted in the analytical frameworks so far used for prioritizing livestock research at ILRI. These were identified through a review of existing documents as reported in the preceding section and using informal feedback from users of the current tools. The identified gaps are mostly related to limitations in the data and methods used, including in the choice and calculation (and in some cases omission) of indicators used to assess the potential socioeconomic and environmental outcomes of candidate research options. The basic approach adopted for improving the prioritization framework was to identify options for upgrading the data, tools and methods. Another area for improvement of the prioritization framework is in its alignment to emerging objectives of the global development community and to conceptual representations of how future research will be translated into desired development outcomes. There is some overlap between these two main ideas in that data and methods that improve on quantitative measures of research impact can be adapted to assessing adherence of candidate research options to end-user objectives, as well as the tracking of their potential translation from research activity to expected outcomes. Two main improvements are thus proposed to the prioritization framework. First, we propose to improve the choice of impact indicators to better reflect research impact pathways or somewhat account for their underlying assumptions. Second, we propose to improve on the calculations of the expanded set of indicators. This necessarily calls for some updating of the underlying data.

Figure 1 is a schematic of an improved framework for research prioritization that incorporates suggested extensions of the Thornton-Randolph-McCleod framework (Thornton et al. 2000; Randolph et al. 2001; McCleod 2016). Emphasis has been placed on extending the assessments to incorporate foresight trends and scenario analysis and updating the ex-ante quantification of socioeconomic benefits and environmental impacts. These have been done through inclusion of IMPACT, a global sectoral multi-market model with a long-run outlook on agriculture and food system (Robinson et al. 2015)agriculture, and natural resources at global and regional scales. IMPACT is continually being updated and improved to better inform the choices that decisionmakers face today. This document describes the latest version of the model. IMPACT version 3 expands the geographic and commodity scope of the model in response to desires expressed by researchers and policymakers to address more complex questions involving climate change, food security, and economic development into the future. IMPACT 3 is an integrated modeling system that links information from climate models (Earth System Models, and its extensions to environmental and socioeconomic (employment) impact assessment. Details of the suggested improvements are discussed below.

Figure 1: Schematic of suggested improvements to Prioritization Framework of the Livestock CRP



3.1 Expanding the choice of indicators

As institutions like ILRI become more impact oriented, there is incentive to align all research and related activities, and as such research prioritization, to this end goal. There has been reasonable alignment of previous ILRI research prioritization tools to the objectives of international development. However, goals for international development have since become even more clearly articulated, including in the form of the CGIAR system level objectives (SLOs) and intermediate development outcomes (IDOs) (CGIAR 2015)and benefits are likely to go as high as 17 times costs as they are harvested over the lifetime of projects.iv Just over half of the world's rice land is sown to high yielding varieties derived from CGIAR breeding materials. Launched in 2006, Drought Tolerance Maize For Africa (DTMA. These updates need to be better captured in the prioritization of research options, so research programs and activities can remain relevant to the aspirations of key stakeholders including decision-makers and final beneficiaries. Within ILRI, the results strategy framework and IDOs of the (earlier) Livestock and Fish CRP outline six key objectives by which candidate research options could be compared. These outcomes are related to productivity (of livestock), agricultural/food supply, employment and incomes, nutrition, the environment and policy.

Much of the anticipated benefits to investing in livestock R&D hinge on the capacity of governments and development actors to channel growing opportunities in the sector to poor producers (Staal et al. 2009). These opportunities need to be adequately analyzed to account for the different trajectories of demand for livestock products that emerging producers could face. Better evidence is needed to help planners make the decision to focus research for development on livestock species or food products for which there is the greatest anticipated demand and/or the most opportunities for smallholders. Alternatively, research managers may want information on the robustness of available research to select options that likely prevail better under a myriad of plausible future trends of economic or environmental change (Enahoro et al. 2019).

In addition to assessing the potential of research streams along such objectives, there is need to assess some of the assumptions underlying translation from research to impact. Using a simple example, where a research activity anticipates poverty reduction from the introduction of a livestock vaccine, it seems logical to assess aspects from the potential for the vaccine to be made available and accessible to poor farmers, to prospects for equitable participation of the farmers in markets given their enhanced production capacity. Within the theory of change of the Livestock and Fish CRP, technological innovations; tools, methods and development of value chain assessments; and strategies for research out scaling are translated into SLOs and IDOs through partnerships and capacity building, amongst others.

Table 2 outlines key development objectives and their enabling factors as defined in the IDOs of the Livestock CRP (Livestock and Fish 2013) and maps these to the analytical tools and methods proposed for research prioritization in the Livestock CRP. As shown in the table, integrated assessment models confer the major advantage of explicitly quantifying variables previously assessed only using rankings obtained from expert opinions. While expert opinions often provide valid alternatives to data-rich approaches (Kamali et al. 2017)the validity of expert opinion used to score sustainability performance of agricultural systems, however, has not been addressed. Also, robustness of the overall outcome of MCA to uncertainty about scores obtained from expert elicitation and weights used to aggregate scores is generally not addressed. The objectives of this study were to evaluate the validity of expert opinion, and to evaluate the robustness of the overall MCA outcome to uncertainty about scores and weights. The case study considers three soybean agricultural systems in Latin America: conventional agricultural system, with either genetically modified (GM, they may be lacking somewhat in objectivity and are more limited tools for parsing out complex interactions. This is the case for factors related to climate change, environmental impact and the use of natural resources for which outcomes are not always linear and may involve complementarities and trade-offs. The integrated assessment models proposed will provide formalized and more robust frameworks for understanding these complexities as they will likely be associated with future interventions in the global food and agricultural system (Islam et al. 2016).

Table 2 describes that linked integrated models will improve assessments of the existence and nature of future markets for livestock products, measurement of the impact of candidate research options on smallholder producers and national employment pools, the role of policy research and how well national or other policies (e.g. technological) interventions fare and factors affecting the dissemination and adoption of new technologies. Integrated models are also recommended for generating comparable numbers on impact of research on human diets and nutrition, environment, cross-border outcomes and trade-offs between multiple objectives. Although the channels through which research innovations eventually deliver benefits to intended beneficiaries can be quite complex incorporating numerous feedback loops that may be very different depending on the focus of the research (e.g. technology, natural resources or policy) (Briones et al. 2004), they can be well captured using analytical tools specifically designed for such contexts (Lie et al. 2018; Rich et al. 2018). In addition to the tools specifically tested, system-dynamic models deliver these assessments on much finer spatial scales than the national level focus of this exercise, potentially generating measures of research impact that are otherwise difficult to capture in global- and country-level multi market models. These methods are also well adapted to policy analysis and to assessing potential impacts of R&D interventions on youth, gender and related outcomes.

3.2 Updating data

Improving measurements of the ex-ante impact indicators to better reflect developmental objectives or account for impact pathways will require not only adopting and adapting new models and methods, but also the updating of existing databases to work with these tools. Ongoing research at ILRI remains a major source of data to inform prioritization of research. For example, comprehensive collations of generated evidence on the performance of agricultural technologies generated from lab and field experiments have been useful for simulating yield productivity gains in IMPACT. Data and integrated assessments built around them have also been useful for testing the potential for competing technologies under opportunities and constraints brought on by major shifts in global conditions (Islam et al. 2016; Robinson et al. 2015; Multi-Funder Group 2018). These types of data and modelling have been more readily organized for crops than for livestock (Msangi et al. 2014), although efforts are ongoing to simulate livestock yield gaps (and options for closing them) within integrated assessment and global models (Herrero et al. 2016). Models such as the DynMod herd model (Lesnoff 2008), useful for translating information on potential change in livestock herd productivity to relevant parameters for economic analysis, has also been coupled with IMPACT (Toye et al. unpublished). The data generated from these studies are available for adaptation to the current context, even if of limited global coverage.

An enduring criterion for useful livestock research is its capacity to provide direct benefits (e.g. income, employment and nutrition) to smallholder producers. Updated data on the characterization and spatial location of livestock keepers help inform the assessment of these goals. The World Bank's Living Standards Measurement Surveys (LSMS) and the Demographic Health Surveys (DHS) program both generate relevant data. These are available for many target countries of ILRI and the Livestock CRP. Data from DHS was recently used in assessing the potential of the livestock sector to supply nutrition and livelihoods in the Livestock CRP countries in Africa (Enahoro et al. 2018). Quick databases have also been generated using the nationally representative household surveys to improve on previous counts of the populations of poor households that could potentially benefit from interventions in livestock research and development.

Advances in data management, including the collection, sharing and use of large datasets to improve the availability and quality of livestock data mean that some of the earlier quantitative assessments can be revisited to provide better estimates of expected impacts of research. Updated measures of research impacts on income, nutrition, health, poverty, livelihoods or employment can then be fed into ranking processes that compare one intervention pathway against another.[4] The criteria weighing methods earlier used (i.e. Thornton et al. 2000; Randolph et al. 2001; McCleod 2016) could be updated to incorporate ranking approaches employed in other studies. These other approaches include a data-driven approach to identify countries and interventions where additional resources could have a lasting impact (Kharas et al. 2017), systems approaches simulating simultaneous impacts to different components of the agriculture and agri-food system (Kulshreshtha et al. 2000; Lie et al. 2018; Rich et al. 2018), the use of efficiency criteria that directly link interventions to aspects of productivity (Allen and Parker 2012), and methods that incorporate locally specific trade-off analysis (Schindler et al. 2016).

A major shortfall of the earlier analysis was addressed in the use of Monte Carlo methods to model inherent uncertainties around point estimates such as potential gains in livestock productivity and probability of research success (Randolph et al. 2001). As such, appropriate confidence intervals, rather than single-point estimates were used to represent these key variables when selecting among candidate research themes, providing more robust measures. However, key limitations exist in the use of the economic models.

3.3 Expanding quantitative assessments

It is recommended that economic surplus (ES) models remain integral tools in the prioritization of research interventions at ILRI as they provide quantitative and precise economic information that decision-makers can use for candidate options under consideration. One such ES model is DREAM— a readily available partial equilibrium, single commodity, multi-region, economic surplus model developed by IFPRI. DREAM is useful for assessing the potential economic benefits of technology diffusion and adoption. An online version provides a simple interface that users can employ to input relevant parameters for calculating potential costs and benefits of different technological change under

4. For convenience, 'research activity' is used as an all-encompassing term. However, prioritization of livestock research could be over disciplines, research themes, focus countries, site locations, etc.

(user defined) market, technology, policy and other scenarios (HarvestChoice 1995). The use of global economic models such as IMPACT should complement, and not replace, this suite of ES models.

Among other limitations in the earlier use of ES models, a closed economy assumption was adopted in the calculation of economic benefits so that potential production and consumption of livestock food product commodities were accounted for within the target country but not for other countries. However, it has been observed that regional and global outcomes impact significantly on the dynamics of local livestock markets (Enahoro et al. 2019). The models used for livestock research prioritization at ILRI have also typically not factored in possible differentiation in products (e.g. low versus high value meat cuts), markets (e.g. poor versus rich or urban versus rural consumers), market distortions (e.g. subsidies and taxes), or added cost to farmers from production of new technologies in the calculation of socioeconomic impacts. Moreover, price elasticities, i.e. the responses of consumers to price changes of livestock sector goods and services, have not reflected livestock system-specific or spatial differences. Other identified gaps are that future trends (e.g. product demand, supply or prices) have been limited to the short horizon and economic feedbacks and complex interactions largely ignored. These factors may create opportunities or impose constraints that ideally should be assessed when considering alternative interventions. Some of these gaps (not all) are addressed in detail in upcoming sections.

Scenario modelling using IMPACT

IMPACT—the international model for policy analysis of agricultural commodities and trade—is a system of linked economic, water and crop models supporting the integrated analysis of changing environmental, biophysical and socioeconomic trends related to the global agricultural and food system (Robinson et al. 2015). At the core of the model is a partial equilibrium, multi country multi commodity model. IMPACT has been applied to a variety of issues of relevance to policymakers from national to global levels regarding trends in the demand, supply and trade of agricultural and food commodities; and the welfare of the systems, people and natural resources associated with these trends (Rosegrant et al. 2015; Robinson et al. 2015; van Soesbergen et al. 2016; Rosegrant et al. 2017; Multi-Funder Group 2018; Mason-D'Croz et al. 2019). IMPACT has been used to analyze the long-run impacts of interventions in the global agriculture and food system, including changes stemming from agricultural research and development. Its use in assessing livestock-focused interventions has been more limited (Delgado et al. 2001; Rosegrant et al. 2013; Enahoro et al. 2019) although updates to improve the model's specification could see its greater application to livestock analyses (Msangi et al. 2014; Enahoro et al. 2017).

Major advantages IMPACT can bring to the current prioritization framework are: (1) quantitative projections of key trends and potential impacts allowing for decision-making to incorporate longer term perspectives (currently to year 2050); (2) interlinked modelling of socioeconomics, agriculture and natural resources aiding joint assessments of multi-dimensional impacts; and (3) simultaneous assessment of multiple agricultural and food commodities and regions (including their interactions) resulting in better accounting for international trade and cross-border impacts of proposed sector interventions. Also important is the capacity of the model for scenario analysis, which is the model's core strength. IMPACT specifically allows for alternative scenarios about how human population, income, climate change and other major drivers may change over time, providing "what-if" scenarios that decision-makers can test proposed technological interventions against (Islam et al. 2016). However, the model is not sufficiently disaggregated to account for differences in production systems or producers, differentiated consumers or products, or sub-national impacts. Feedback of the agricultural and livestock sector with other sectors of the economy are ignored, and youth or other demographics useful for assessing issues of equity are not factored.

For a candidate research option appropriately simulated in IMPACT, the model will generate quantified indicators that can be compared across alternative investments and for a no investment (research) world. Table 3 presents standard outputs from the multi-market model. Indicators of interest include demand, production and trade of agricultural commodities, food supply, availability and accessibility and measures of hunger and nutrition. IMPACT model results have also been extended to project long-term benefit-cost ratios and returns to investment (Rosegrant et al. 2015), greenhouse gas emissions and other environmental indices (Rosegrant et al. 2017), supply of key food nutrients

(Enahoro et al. 2018; Rosegrant et al. 2017) and risks of food-related noncommunicable diseases (Springmann et al. 2016). Two of such extensions are considered here: the linking of national-level trends on livestock demand, production and trade to environmental impact at landscape and national levels, and the assessments of welfare impacts. The assessment of environmental impact is based mainly on feed use and availability, while welfare impacts track employment.

Environmental impact assessments

A methodology is proposed for analyzing a range of environmental impacts associated with the initial national-level results obtained from IMPACT. This methodology is based on linking IMPACT outputs to CLEANED—an environmental impact assessment model. CLEANED is a spatially explicit simulation tool that can compute water use, greenhouse gas emissions, biodiversity loss and nitrogen balance of a given landscape using input data on evapotranspiration, crop yields, climate suitability, climate, soils and land cover, amongst others (Pfeifer et al. 2016). These data are inputted into the model from a variety of open access georeferenced data. In a test of the model integration, IMPACT simulations provide a set of user-defined parameters to CLEANED as input. CLEANED uses these IMPACT results on crop and livestock production in its computation of land use changes related to livestock production. To do this, it employs rules for land cover changes that are country specific (Pfeifer et al. 2018). The IMPACT-CLEANED model linkage is documented in Pfeifer and Enahoro (2017) for landscape and in Pfeifer (2018) for national analysis. Results from the test applications are summarized in Section 4.

Welfare modelling

Frija and Enahoro (unpublished) propose an elasticity-based methodology for translating GDP growth resulting from livestock R&D investments into estimates of new employment. Employment figures from future GDP growth are calculated using relationships earlier established in Alene et al. (2009). For each country and (global agricultural) investment scenario analyzed, employed populations are calculated from GDP growth rates using the concept of elasticity of employment or employment intensity of growth. This macroeconomic measure can refer to the growth of the whole economy, or of a single sector such as livestock. Net benefits of candidate livestock investment are estimated as the difference between GDP outcomes with and without investments in livestock. However, unlike the capabilities that a standard Computable General Equilibrium (CGE) model confers, this methodology does not account for important features of anticipated economic changes such as those impacting or resulting from differences in labor, skillset or education in the livestock and other agriculture or non-agriculture sectors. It provides estimates useful only for broad-brush assessments of how competing investments into agriculture/livestock will perform on key aspects of welfare. The methodology is presented in full in an accompanying report that includes relevant sources of employment data and overall macroeconomic descriptions for a selected set of African countries (Frija and Enahoro, unpublished). The report also presents the analyses of a few selected global R&D investments earlier reported in Rosegrant et al. (2017) with application to Tanzania and Burkina Faso. Section 4 presents a summary of the results.

General equilibrium modelling

The previous sections (and past research) have focused primarily on the use of partial equilibrium techniques, whether single sector or multi sector, in the computation of R&D benefits to prioritize livestock investments. However, it is worth motivating and exploring the use of general equilibrium approaches coupled with the sector-level detail provided by ES models such as IMPACT. For example, in recent years, a number of social accounting matrices (SAM) developed by IFPRI have been providing more granularity in the disaggregation of the livestock sector, considering multiple species and products, and expanding the remit of distributional analysis, including "gendered" SAMs (Randriamamonjy and Thurlow 2017). At a minimum, these provide insights on the scale of livestock "multipliers" within an economy, which can be ranked across different sectors to quantify how exogenous spending by public or private sectors in livestock compare to other agricultural or non-agricultural sectors (Roeder and Rich 2009; de Haan et al. 2018), although these analyses can go much farther. In an impact assessment of African Swine Fever, Nguyen et al. (2019) combined the use of a multi-market model at the level of pig-maize sector impacts in conjunction with a SAM of Viet Nam that was used to explore distributional, macroeconomic (GDP), and employment impacts, with the latter considering the number of jobs lost under different disease-related shocks to the pig sector. At its most complex, the development of CGE models using these enhanced SAMs combined with herd dynamics could provide even more guidance on priority setting[5].

4. Case applications

The improved framework was pilot tested for the prioritization of country and livestock value chain combinations to be included in the livestock CRP. Data on a range of livestock sector and value chain characteristics were collected and analyzed for seven countries. Moreover, IMPACT model outputs were analyzed for two of these countries and extension of the IMPACT modelling to environmental impact and employment impact simulations implemented. The details of these activities are as follows.

4.1 Data for country and value chain selection

Data was collected using a quick collation process to inform the country and (livestock) value chain focus of the Livestock CRP. Previous work already defined the livestock value chains within the target countries that the Livestock CRP will focus on (ILRI et al. 2016). Six of the (initially 7) target countries of the CGIAR research program on Livestock and Fish—Burkina Faso, Ethiopia, Tanzania, Uganda, Vietnam and Nicaragua—were included in the data collation (India was excluded). Kenya, previously not a Livestock CRP country, was included as a good candidate country for the next phase of research programs. The country selection followed discussion with senior management of the research program. Data on numbers and characterization of livestock keepers, including livestock assets and herd sizes, were used to determine the potential reach of ILRI's research amongst poor populations. Table 4 presents a selection of statistics for these livestock sub sectors and countries that are useful for further assessing their relevance for livestock research prioritization.

While small ruminant meat production accounts for 0.12% of the economy of Ethiopia, nearly 15 million poor people in Ethiopia owned sheep or goats in 2011, suggesting that improving the value of the sub sector has potential to reach many target households. Data show that 36% of all poor livestock keepers in Ethiopia keep small ruminant animals. In comparison, production in Kenya's dairy sector contributes as much as 2.5% of the national GDP with more than six million poor livestock keepers keeping dairy animals, which is 38% of livestock farmers in the country. Increased supplies of livestock-derived foods (LDF) stand to benefit more than five million poor consumers in Kenya and close to 22 million in Ethiopia. The livestock value chains in different countries offer unique opportunities that international livestock research could focus on, depending on which overall objectives (among the SLOs) are paramount.

4.2 Impact assessment

Amongst other criteria, the selection of countries and livestock sectors to focus on should consider the potential for widespread benefits to poor producers and consumers. No specific interventions regarding livestock technologies or research themes were analyzed. Instead, the outputs from standard scenarios previously quantified in IMPACT were adapted in novel ways using the tools and methods described in Section 5. Outputs representing varying conditions of economic growth and other major trends affecting the livestock sector were generated using the IMPACT model. These were then used to assess national and multi-country regional demand for LDF that smallholder producers could potentially target. The model outputs were further analyzed to compare countries in terms of future food security;

this was then extended to the simulation of potential environmental impact and poverty reduction opportunities. All countries of the Livestock CRP were included in the analysis of standard IMPACT results (i.e. LDF demand and supply and food security), while only two countries (Tanzania and Burkina Faso) were included in analyses measuring environmental and employment impacts. The resulting estimates are presented to demonstrate possible application to other assessments or prioritization.

Economic impact assessment

For seven countries for which the global model projections were assessed, the demand for livestock-derived products is anticipated to be higher in 2030 as compared to 2010. With this demand could come livestock value chain growth and transformation, and presumably opportunities for local producers. However, where farm-level production is not well connected to increases in demand through formal markets, these opportunities may not necessarily be beneficial to local or smallholder producers. Table 5 shows scenario projections of the total (national) demand by households in 2030 for LDF types thought to hold potential for pro-poor development in the various countries. The total demand for dairy is higher in Kenya than it is for Tanzania under all scenarios (of global economic growth) assessed. However, production in Tanzania is projected to fall short of demand whereas Kenya may be on course to surpass local needs. Similarly, pork production covers national demand in 2030 in Vietnam but not in Uganda. If national self-sufficiency of these products are goals of food security for the countries involved, the data highlights immediate gaps in Tanzania and Uganda that livestock research could look to fill. Taking a more regional perspective, East Africa as a region is projected to produce enough dairy to meet consumption needs, while possibly raising the importance of research to support interregional dairy trade and distribution. This is the opposite for pork. Moreover, demand gaps may be more pronounced under certain scenarios of economic development. For example, milk demand is much lower in Kenya under the optimistic economic growth scenario (SSP1) than in the baseline (SSP2) or pessimistic (SSP4) scenarios. This is likely reflecting the effects of a booming global economy on local prices (Enahoro et al. 2019). Research and other interventions in the dairy sector will likely need to focus more on consumption and nutrition impacts of international trade in Kenya than in Tanzania.

IMPACT model projections were further used to assess demand and supply trends of LDF up to 2030 in two Livestock CRP countries—Tanzania and Burkina Faso. Three model scenarios were analyzed: one of continuing economic and climate trends from 2010–2030, an optimistic future with improved economic outlook; and another pessimistic future with dampened economic growth to 2030. These results had previously been generated for a CGIAR-wide project under the Policies, Institutions and Markets (PIM) program (Enahoro et al. 2018) and are readily available, partly informing the choice of countries. In Table 6, estimates are presented of key model projections relevant to the livestock sector. Only baseline results depicting a continuation of current trends of economic and related conditions are included. Income per person is both higher (slightly) and projected to grow by more from 2010–2030 in Tanzania than in Burkina Faso. This is an important statistic since income growth is one of the key factors identified in low- and middle-income countries (LMIC) increasing their consumption of animal source foods (Delgado et al. 2001). In addition, although population is projected to grow faster in Burkina Faso, it will remain higher in absolute numbers in Tanzania. Higher numbers of people as well as increased incomes in both countries suggest scope for livestock sector expansion. In addition, both countries have a large pool of rural populations (not shown in table), implying opportunities for rural-based development. However, the model projections suggest LDF demand will be more responsive in Burkina Faso, growing by more on a per head basis for milk, beef and poultry. Level quantities and anticipated growth in livestock feed demand in Tanzania far exceeds that projected for Burkina Faso. However, this does not imply livestock-related environmental impact will be more pronounced in the former. Measures of environmental impact have been conducted within the case studies.

Quantifying environmental impact

An initial exercise linking the IMPACT model to CLEANED for assessment of Bama (a region in Burkina Faso) (Pfeifer et al. 2018), led to useful information on how well (or not) global model projections can match to stakeholder aspirations for local food production and the management of underlying resources. The results were useful for determining the focus of livestock research within country but had more limited use for prioritizing research investments between countries. The CLEANED model has subsequently been adjusted to enable environmental impact assessment (of IMPACT scenarios) at country level. Pfeifer (2018, unpublished) reports on the findings when measures of animal source food demand simulated under different assumptions of 2030 (Robinson et al. 2015) agriculture, and natural resources at global and regional scales. IMPACT is continually being updated and improved to better inform the choices that decisionmakers face today. This document describes the latest version of the model. IMPACT version 3 expands the geographic and commodity scope of the model in response to desires expressed by researchers and policymakers to address more complex questions involving climate change, food security, and economic development into the future. IMPACT 3 is an integrated modeling system that links information from climate models (Earth System Models are passed through CLEANED to inform country prioritization for livestock research. The integrated assessment tool was applied at national scale to Burkina Faso and Tanzania (Pfeifer et al., unpublished). Figure 2 presents plausible environmental impacts of higher LDF demand in Burkina Faso and Tanzania, with and without complementary gains in crop productivity. In Burkina Faso, the grazing area needed for production of livestock feeds under baseline demand for LDF in 2030 is 73% more than currently available. It is 100% more under the optimistic scenario and 50% more under pessimistic economic growth conditions. This suggests the feed baskets need to change for the country to reach the production levels needed for domestic consumption (and perhaps highlights the relevance of livestock feeds research going into the future). With crop productivity gains simulated, all three IMPACT scenarios were found to be within carrying capacity, i.e. enough biomass is produced in Tanzania. Only marginal estimates of additional crop area are needed in 2030. Because there is no productivity gain on grasslands, there is an increase in grassland area needed to source natural feed and fodder. These areas are available, and all scenarios are within carrying capacity. In the scenario without crop productivity gains, more cropland is needed beyond the carrying capacity of Tanzania, suggesting that about 2–5% of the biomass from croplands needs to be imported. The optimistic scenario has the most animal source production, uses more resources (land, water) and has the highest impact (greenhouse gas and nitrogen balance). In the case of Burkina Faso, additional work is needed to find a feasible feed basket that allows to produce enough LDF for the country. The IMPACT-CLEANED assessment of standard IMPACT scenarios could suggest that Tanzania will be a better alternative than Burkina Faso for investing in technological and other options that will likely expand livestock production. However, the findings can also be interpreted as indicating a need to prioritize feed and forages R&D alongside national-scale initiatives to increase livestock production/consumption in Burkina Faso.

Quantifying impact on employment

The ex-ante assessment of impact of the same economic growth scenarios as in the environmental impact assessment above was tested on employment for Tanzania and Burkina Faso. The three considered scenarios refer to Shared Socioeconomic Pathway 1 and Representative Concentration Pathway 6.0 considered as optimal demand scenario; Shared Socioeconomic Pathway 2 and Representative Concentration Pathway 6.0 considered as the base demand scenario; and Shared Socioeconomic Pathway 4 and Representative Concentration Pathway 6.0 considered as the pessimist demand scenario[6]. Economic growth effects of these three scenarios were simulated using the GLOBE CGE model is a model linkage between IMPACT and GLOBE (Rosegrant et al. 2017). As described in Section 5, employment outcomes were generated by applying an elasticity-based transformation to the GDP growth changes that resulted from livestock R&D investments.

In Burkina Faso, the baseline scenario assumed growth in GDPPC by 404%. In Tanzania, the baseline growth was 447%, projecting similar (and substantial) growth in consumer incomes for both countries. Compared to the baseline results, GDPPC is higher by 68% in Burkina Faso and by 67% in Tanzania under the optimistic scenario. It is lower by 54% and 49% in Burkina Faso and Tanzania, respectively, under the pessimistic scenario . As such, the income projections are slightly more variable for Burkina Faso than Tanzania. The value of livestock production changes in similar ways in both countries. Projected impact on employment is more pronounced for Burkina Faso. Compared to the base scenario, employment numbers are 7.12% higher under optimal scenario and 7.68% lower under pessimistic scenario. This means, compared to the baseline, many more jobs could be created/lost as the economy expands or contracts. Growth in employment in Tanzania is 7.1% higher under optimistic and 7.3% lower under pessimistic. With no specific livestock interventions tested for the two countries, the results suggest there is greater agreement between the scenario projections for Tanzania than for Burkina Faso, and livestock impacts will be more stable in Tanzania. However, it will be useful to quantify livestock-specific investment scenarios, assess their respective impacts on livestock productivity and agricultural GDP growth and generate more concrete figures on potential employment creation associated with livestock R&D options.

5. Conclusions and next steps

An exercise was carried out to identify gaps and potential improvements of the existing frameworks for research prioritization in the CGIAR research program on Livestock. Improved analytical tools have been developed from this exercise, and data and results were provided from limited test applications. To a lesser extent, factors influencing the translation of research to desired outcomes are incorporated into the prioritization framework. Effort was made to include assessments of some facilitating factors included in the theory of change of the Livestock CRP. We do not have enough material to offer an updated framework as a complete tool but we provide useful recommendations on how improved data and tools can be utilized and what else could be done to make the framework more complete. The test application offers quantitative estimates (or methods for determining these) that improve objectivity of the assessments of individual factors considered in prioritization.

Case applications of the improved framework identify significant prospects for socioeconomic impact (e.g. on food security and employment) in a country such as Burkina Faso, while highlighting the potential risk of increased negative environmental impact. A sustainable strategy to expand livestock R&D activities in such a situation will need to include considerations for livestock feed development and land use management. Databases and analytical tools were developed mainly for the Livestock CRP target countries. However, it is anticipated that a follow up set of integrated data and models will be more generic and adaptable to assess research priorities in other countries and contexts. The models used in this exercise are not applicable under all contexts in which prioritization of livestock research will be done at ILRI or in the Livestock CRP. They are also less appropriate for inferring economic effects at the macro level. While the IMPACT, CLEANED and Poverty models proposed here may be well suited to decision-making regarding country selection, or between large programs with multi-country implementation and/or impact, they are less useful for prioritizing finer details within these broader choices. A specific area for development will be to link the spatial layers in CLEANED explicitly to spatial data underlying livestock feed production in IMPACT. In addition, the economic modelling will need to be revised to better accommodate links of the livestock sector, and livestock research, to the broader economy.

An important component of analyzing research options under changing global demand for livestock-derived foods, i.e., data on price elasticities, was not treated. Moreover, youth and gender outcomes of candidate technologies or interventions, which remain particularly challenging to quantify, have not been captured. For example, it is well documented that factors that enhance or constrain livestock-related opportunities for women have received relatively little empirical analysis yet the factors that enhance or constrain livestock-related opportunities for women have received relatively little empirical analysis. This review applies a gender lens to a conceptual framework for understanding the role of livestock in pathways out of poverty, using a livelihoods approach that centralizes the importance of assets, markets, and other institutions. The three hypothesized livestock pathways out of poverty are (1(Kristjanson et al. 2014), leaving a historical gap between what questions need to be answered about new or potential research and the current capacities of integrated assessment models. However, analyses of candidate livestock research options with difficult-to-simulate dimensions may still rely to a large extent on expert opinions as adopted in the previous assessments. These processes can be upgraded through (1) use of highly knowledgeable groups of experts; (2) expanded pools of experts (Pashaei Kamali et al. 2017); and (3) keeping abreast of developments in the deployment of standard integrated assessment models. Another area that will benefit from committed resources is the expansion of existing datasets on livestock yield gaps and the potential for technology to close these gaps. More attention also needs to be paid to characterizing major drivers of change in the livestock sector and how investments in livestock R&D contribute to or are impacted by these.

Lastly, it is important to understand who (such as research funders and policy makers) will be making key decisions using the prioritization results and what variables will they consider in their deliberation. This is helpful to ensure that factors influencing final decision-making are being duly addressed. It may also mean identifying specific variables that final decision-makers will be making decisions on and providing this information in the appropriate and usable formats.

Table 1: Summary of key aspects of research priority setting frameworks at ILRI, 2000 to present

Exercise	Unit of analysis	Objectives/criteria assessed	Tools used to assess the objectives	Prioritization methodology
Thornton et al. 2000	Research streams constituting the institute's research themes	Poverty reduction	Poverty indices*	Delphi approach used to validate and harmonize the assessment of individual research streams Composite index derived for each theme and weighted according to selected criteria
		Economic impact	Economic surplus model (Alston et al. 1995)	
		Impact on the environment, public health (zoonosis) and biodiversity of plant and animal resources	Environmental impact (weighted) scoring	
		Internationality of problem	Simpson index of diversity (scoring) based on spread of economic gains	
		Capacity development, new research tools, research efficiency	Weighted scoring based on expert knowledge of candidate research streams	
Randolph et al. 2001	Research streams constituting the institute's research themes	Poverty alleviation	Same as Thornton et al. 2000	Monte Carlo sampling of probability distributions imputed to uncertain input variables (e.g. probability of research success); Composite index derived for each theme and weighted according to according to selected criteria
		Economic impacts	"	
		Environmental impact	"	
		Internationality of the problem and solution	"	
		Contribution to capacity building and improved research efficiency	"	
McCleod, 2016	Research streams constituting CRP flagships and clusters	Poverty alleviation	Uses the results from Thornton et al. 2000	Composite index derived for each theme and weighted according to selected criteria
		Economic impacts		
		Environmental impact		
		Internationality of the problem and solution		
		Contribution to capacity building and improved research efficiency		
		Inclusiveness: youth and gender	Scoring	

*Type of poverty (urban vs rural), extent and severity of poverty and societal inequity

Table 2: Matching research prioritization approaches to IDOs and some important underlying assumptions

Intermediate development outcomes (IDOs)	Selected assumptions or underlying factors[i]	Treatment in Thornton et al. 2000 (T2000)/ Randolph et al. 2001 (R2001)/Mc Cleod et al. 2016 (M2016)	Extension to IMPACT, CLEANED and Employment modelling	Next steps/still outstanding
Increased livestock productivity in small-scale production systems for target communities	The innovations are successfully developed	Probability of research success specified in the economic surplus (ES) model, R2001 further used Monte Carlo methods to simulate the uncertainties brought on by this variable	None	No change suggested
	Effective channels for research dissemination are, or will be in place	Extension costs are factored in the ES model but not the effectiveness of extension (e.g. how robust are public network extensions in target areas/amongst target populations)	A range of dissemination strategies can inform adoption relationships simulated in IMPACT as well as in standard ES models (e.g. HarvestChoice 1995)[ii]	Being able to distinguish extension from uptake effects on observed adoption rates may be useful for quantifying the extents and cost of complementary investments that will be needed alongside new technologies
	Accessible technologies will be appropriately adopted by target users	Adoption curves and rates are specified in the economic surplus model		
Increased quantity and quality of the target commodity supplied from target production and marketing systems	Adoption of innovations will lead to increased supply and improved food availability	Growth in commodity production (and consumption) specified as parameters in the economic model's calculations of benefits and costs (e.g. Alston et al.1995 used in M2016)	Primary results from IMPACT include commodity supplies (from local production and imports), demand, trade and prices. Measures of food security: availability, hunger and malnutrition are also provided with the primary results	Ongoing IMPACT model improvements will distinguish national supply by (originating) livestock production systems. Disaggregation of the model's livestock commodities and use of other modelling (e.g. computable general equilibrium—CGE) that can link agriculture production to more economy wide changes, could provide ways to model changes in commodity quality
	Appropriate markets exist/ will be available in the future that smallholders can service (this row also applies to the IDO on incomes and employment)	Alternative market parameters such as market size, elasticities, etc. can be specified within the ES models	Alternative market parameters such as market size, elasticities, etc. are specified within the ES models. Scenarios of future demand can be assessed using IMPACT	More work is needed to assess the specific capacity of smallholders to access formal markets. Production system disaggregation in the IMPACT model could help; but also (particularly) extension of the framework to include other analytical tools and methods, such as system dynamics modelling and value chain analysis.

Intermediate development outcomes (IDOs)	Selected assumptions or underlying factors[i]	Treatment in Thornton et al. 2000 (T2000)/ Randolph et al. 2001 (R2001)/Mc Cleod et al. 2016 (M2016)	Extension to IMPACT, CLEANED and Employment modelling	Next steps/still outstanding
Increased employment and income for low income actors in target value chains	Expanded opportunities are generated for target producers	Producer and consumer surpluses as well as poverty reduction impacts assessed directly and indirectly using the ES models, but no specific calculation of jobs created or enhanced	Extension of the IMPACT model results allows for calculation of employment benefits that could accrue from new research interventions	The simple calculation of changes in employment can be enhanced to better reflect differences in livestock commodities and production systems, e.g. through production systems differentiation in IMPACT. Use of other economic modelling methods can enhance feedback between livestock and non-agricultural sectors, such as mining, manufacturing and services
Target commodity responsible for filling a larger share of the nutrient gap for the poor	Adoption of the innovations will translate to desired dietary changes, e.g. increased consumption of LDF by nutritionally vulnerable groups	Not assessed quantitatively	Asp9ects of diet quality and food use can be quantified using IMPACT	Additional IMPACT model and data development could distinguish urban from rural, or rich from poor consumers of expanded LDF production
Lower environmental impact	Natural capital enhanced and protected, including from climate change	Not assessed quantitatively	Spatial interactions of climate change with land and water resources and with agricultural (crop) yields to be quantified using IMPACT+CLEANED	
	Enhanced benefits from ecosystem services (ESS), improved management leads to increased ESS provision	Not assessed quantitatively	None	Variations of ESS management to be simulated using an extension of IMPACT+CLEANED
Policies supportive to the development of small-scale production and marketing systems, participation of women	The research streams are robust under a range of food policy and other interventions	A range of agricultural and food policies (including limited trade scenarios) can be assessed using standard ES models.	A range of agricultural and food policies (including limited trade scenarios) can be assessed using IMPACT. These interventions can be linked quantitatively to food security, environment and other impacts. Further, the integrated modelling that incudes IMPACT, CLEANED and employment modelling can be applied to testing the robustness of research options under different scenarios of economic, climate and other technological change	Extending the analysis framework to system dynamics and other models well suited to value chain analysis could improve the assessment of policy options, impacts on gender, etc.

[i]These assumptions incorporate IDOs from the CGIAR strategy and results framework (CGIAR 2015)and benefits are likely to go as high as 17 times costs as they are harvested over the lifetime of projects.iv Just over half of the world's rice land is sown to high yielding varieties derived from CGIAR breeding materials. Launched in 2006, Drought Tolerance Maize For Africa (DTMA. They are not exhaustive and represent the interpretations of the authors on key factors needed to realize IDOs of the Livestock CRP.

[ii]Adoption curves were generated for IMPACT for new crop (but not livestock) technologies, as these were considered easier to disseminate over large geographical spaces.

Table 3: Standard model outputs from IMPACT's multi market model

Indicator of impact	Relevant model output(s)	Geographic scope	Time scope
Demand	Total and components: food use, livestock feeds, biofuels, production inputs, other	National	Annual
Trade	Net trade, imports, exports, trade as share of production, as share of demand	National	Annual
Supply	Total supply	National, sub national	Annual
	Harvested areas		
	Livestock numbers		
	Livestock yields		
Accessibility	World prices of food	Global	Annual
	Consumer and producer prices of food	National	
Food security	Kilogram and kilocalorie availability, undernourishment amongst children, total and share of population at hunger risk	National	Annual to 5-year measurements

Source: Robinson et al. 2015.

Table 4: Useful statistics for guiding country and livestock value chain selection/research focus

Country	Livestock sub sector	Percent of total population that is rural	Poor livestock keepers as percent of all livestock keepers	Number of poor farmers that keep the specific LDF	Average herd size in country	Average herd size of poor livestock keepers	Number of "poor" consumers*	Index on importance of LDF sector being assessed**
Burkina Faso	Small ruminants	48%	48%	11,360,793	35.81	33.52	6,252,345	0.91%
Ethiopia	Small ruminants	30%	36%	14,832,427	18.90	37.22	21,886,533	0.12%
Kenya	Dairy	49%	49%	6,333,701	20.58	21.77	5,298,690	2.51%
Tanzania	Dairy	33%	38%	2,063,774	4.42	5.65	13,457,398	0.57%
Uganda	Pig	22%	16%	553,153	1.21	0.70	10,737,157	0.86%

Source: Authors' compilation from various sources, including (Robinson et al. 2011), World Bank data and the DHS program surveys

The statistics are relevant to 2017.

*Number of people in the population that live on less than USD1.9 per day.

**Gross production value of specific LDF (listed in last column) relative to the country's GDP in constant 2005 (USD).

Table 5: Sample IMPACT model measures useful for guiding country and livestock value chain focus

LDF type	Country	Demand for LDF product under SSP* scenarios in 2030 ('000 MT)			Excess production as % demand** (unmet demand as % total demand)					
					National			Multi-country/region***		
		SSP1	SSP2	SSP4	SSP1	SSP2	SSP4	SSP1	SSP2	SSP4
Dairy	Kenya	4,509	4,708	5,051	0.20	0.15	0.06	0.03	0.00	(0.03)
	Tanzania	3,179	3,317	3,375	(0.24)	(0.27)	(0.29)	0.03	0.00	(0.03)
	Nicaragua	508	534	521	0.69	0.60	0.62	(0.10)	(0.15)	(0.14)
Beef	Nicaragua	41	42	40	2.51	2.39	2.49	0.01	(0.03)	(0.03)
Pork	Uganda	286	292	293	(0.33)	(0.35)	(0.35)	(0.42)	(0.40)	(0.38)
	Vietnam	3,936	3,906	3,827	0.02	0.02	0.02	0.06	0.06	0.07
Lamb	Burkina Faso	120	120	119	0.18	0.16	0.16	(0.06)	(0.07)	(0.07)
	Ethiopia	293	292	288	0.16	0.15	0.16	(0.06)	(0.04)	(0.01)

Source: Authors' compilation from IMPACT model results

*The SSPs represent medium rates of urbanization and economic growth (SSP2); fast urbanization rates with (a) inequal (SSP4) and (b) equal (SSP1) economic growth. These three scenarios have been quantified in the IMPACT model (Robinson et al. 2015)agriculture, and natural resources at global and regional scales. IMPACT is continually being updated and improved to better inform the choices that decisionmakers face today. This document describes the latest version of the model. IMPACT version 3 expands the geographic and commodity scope of the model in response to desires expressed by researchers and policymakers to address more complex questions involving climate change, food security, and economic development into the future. IMPACT 3 is an integrated modeling system that links information from climate models (Earth System Models.

**For national production of LDF (column 1) that is more than a country's total consumption, the "excess production" is expressed as a percentage of total consumption (1.0 =100%). When production is lower than consumption, the unmet demand is shown (in parenthesis) as a percentage of total demand.

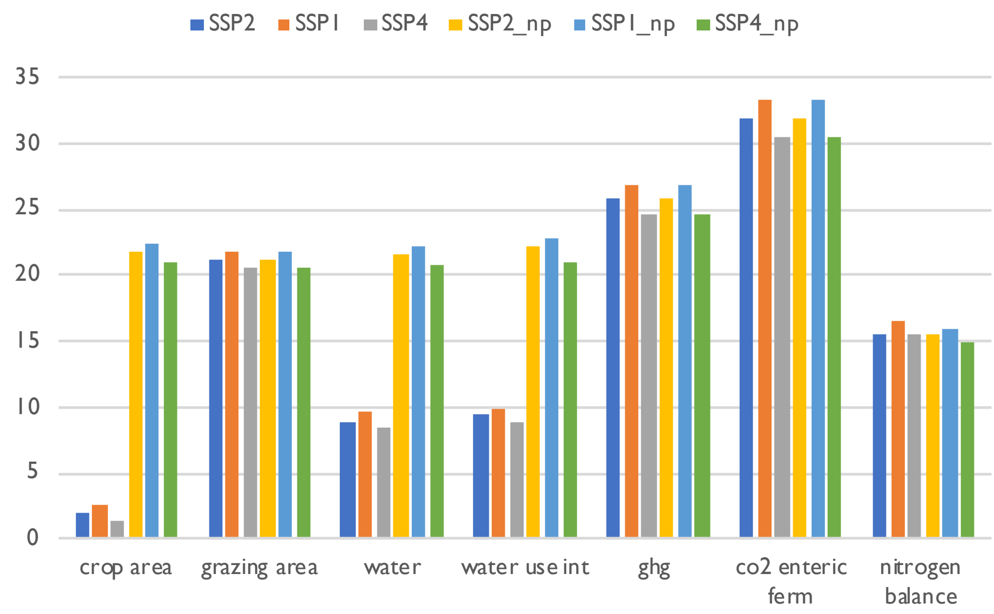
***This is an author-defined cluster of countries that includes neighbor countries in an existing custom or economic union, or where there is potential for future bloc livestock trading.

Table 6: Selected model results of IMPACT baseline scenario for Tanzania and Burkina Faso in 2030

	Tanzania		Burkina Faso	
	Baseline 2010	% change in 2030 (negative)	Baseline 2010	% change in 2030 (negative)
Per capita income, constant 2005 (USD)	1,255	133%	1,136	114%
Population (millions)	44.84	63%	16.46	66%
Share of population at risk of hunger (%)	34.79	(25%)	21.25	(17%)
Number of children <5 who are underweight (millions)	2.35	9%	1.00	14%
Milk demand per person (kg/year)	37.58	21%	16.92	28%
Bovine meat demand per person (Kg/year)	7.41	35%	8.04	83%
Poultry meat demand per person (kg/year)	1.56	74%	2.36	84%
Total feed demand ('000 MT)	1,733	77%	154	69%

Source: Adapted from Enahoro et al. (2018).

Figure 2: Environmental impact for Tanzania, shown as percentage change in 2030 under different scenarios compared to base levels in 2010.



Source: Pfeifer (2018), where "base", "opt" and "pes" represent conditions of baseline (SSP2), optimum (SSP1) and pessimistic (SSP4) scenarios, respectively. Estimates are for with and without (np) the assumption of increased crop productivity.

Figure 3: Average annual growth of employment in Burkina Faso under different scenarios

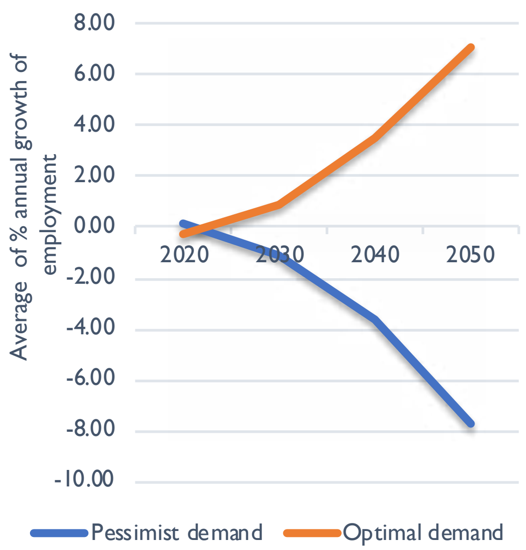
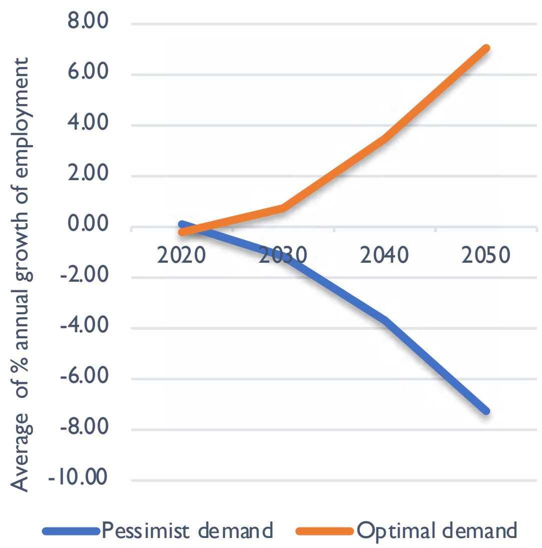


Figure 4: Average annual growth of employment in Tanzania under different scenarios



Source: Frija and Enahoro (unpublished). Pessimist is IPCC's SSP4 scenario, and Optimist is SSP1's. Results are relative to the baseline (SSP2) outcomes.

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