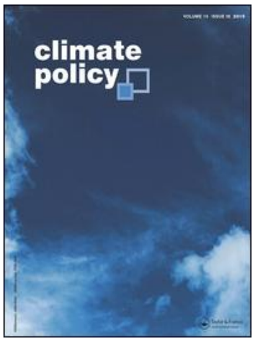

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Participatory modelling for climate change adaptation: the poultry sector in Nigeria

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ABSTRACT
Strategies for agricultural climate change adaptation are needed to ensure that sub-Saharan Africa can continue to feed itself, given its rapidly growing population and the expected impacts of climate change on food production. The poultry sector is an important component of the African food system, but national climate change adaptation plans in many countries fail to take into account the specific contextual challenges faced by poultry producers. We developed a participatory system dynamics modelling tool to involve stakeholders from the poultry sector in Nigeria in analyzing how climate impacts would affect the sector, with the goal of generating insights for state (sub-national) and national scale policy makers. A second goal of the exercise was to facilitate social learning and knowledge sharing on adaptation strategies among the stakeholders. Given the high uncertainty of the conditions surrounding the Nigerian poultry sector, the model's use is primarily as a discussion tool for poultry sector stakeholders, including policy makers, to share concerns and develop adaptation strategies. It served this purpose, as evidenced by the creation of a manual for poultry producers from the exercise. Similar stakeholder engagement efforts can stimulate knowledge sharing around climate change adaptation for problems around which limited data and high uncertainty exist.

Key policy insights:
- Participatory system dynamics modelling is shown to be a useful tool for integrating national and community-level priorities for policy and management under climate change in the Nigerian poultry sector.
- Effective climate change adaptation will require building resilience to large-scale external drivers such as global trade dynamics, which are highly influential in the system.
- In order to effectively move from planning to implementation, climate change adaptation processes must facilitate social learning and knowledge sharing around the long-term consequences of policy and management choices.

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Climate change; climate change policies; participatory modelling; poultry; Africa; complex systems

Introduction

Climate change adaptation refers to 'changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change' (UNFCCC, 2010). To accomplish

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this goal of minimizing harm caused by climate change, many federal, state, and local government authorities around the world have drafted climate change adaptation plans. These plans differ widely in content and implementation strategy depending on local context, but they may include infrastructure projects, changes in government operations, updating communication systems, etc. Most plans require coordination across multiple sectors of society, requiring the public, private and civil sectors to work together (UNFCCC, 2010). Adaptation plans therefore typically include a range of policy, business, management and other strategies to address the impacts of climate change.

Agriculture in sub-Saharan Africa is expected to be heavily impacted by climate change while being tasked with producing enough food for a population that could reach 2.5 billion by 2050 (IPCC, 2014). Most climate change adaptation plans addressing agriculture are drafted at the national level; coordinating adaptation strategies with local stakeholders and across sectors remains challenging (Rasul & Sharma, 2016; Vogel & Henstra, 2015). Recent approaches to climate change adaptation emphasize the need for measures that take into account local context and stakeholder knowledge (Olabisi et al., 2018). Detailed knowledge of the options available for adaptation, and responsibility for implementing those options, will be an imperative for the actors involved, on a daily basis, in food production, processing, distribution, preparation and consumption. Indeed, climate change adaptation efforts will not be successful without integrating the perspectives of actors from various parts of the agricultural system, as changes in one sub-system will affect other subsystems. A participatory approach is therefore crucial for effective and sustainable climate change adaptation (van Aalst et al., 2008).

The poultry subsector is critical for food security and rural economic growth throughout sub-Saharan Africa, and particularly so in Nigeria, Africa's most populous country. The industry constitutes the largest livestock production group in the country, consisting of mostly chicken and turkey, and is expected to bridge the protein gap prevalent in Nigeria (Henke et al., 2015). However, little is known about how the poultry subsector in Nigeria might respond to climate change. Most climate change impact studies in Nigeria and the rest of West Africa have focused on staple food crops, but there is evidence that poultry would be both directly and indirectly affected by increasing temperatures in the region. Higher temperatures can affect poultry growth rates (Gous, 2010; Sanou, 2019), increase mortality (Liverpool-Tasie et al., 2018; Turnpenny et al., 2001) and even reduce meat quality, which could affect consumption patterns (Gregory, 2010). Altered climate regimes could also lead to increased risk of disease outbreak (Gilbert et al., 2008; Jarvis et al., 2012).

Because maize is a major ingredient in poultry feed, particularly for medium to large-scale producers, lower maize yields would cause price ripples up the poultry value chain (Liverpool-Tasie et al., 2020). Most of the maize in Nigeria is produced in the North but this production serves feed mills across the entire nation. Thus, both short term shocks and long term climate change introduce spatial dimensions that will be important factors in the sustainable growth of the subsector in the face of climate change. All of these could lead to loss of livelihoods for thousands of households which depend on poultry sales.

Complicating this picture of climate change adaptation is the rapid development of the poultry sector in Nigeria. Poultry production has expanded rapidly in recent years, partly driven by increasing incomes (Liverpool-Tasie et al., 2016), high rates of urbanization and population growth, and changes in food demand and consumption patterns (Zhou & Staatz, 2016). Poultry is the most commercialized sector in Nigerian agriculture and it is gaining economic momentum. Also significant in Nigeria's agricultural sector are land tenure and land use changes, which could create complex feedbacks with climate dynamics (Yu et al., 2016).

It is extremely difficult for scientists, farmers and other agricultural sector actors to disentangle the relative impacts of these different drivers. This is why a systems approach is needed to better understand climate change adaptation in the poultry sector, as we are proposing here. Nigeria's national plan for climate change adaptation does not mention the poultry sector specifically. The plan does highlight ways in which livestock will be impacted by climate change and proposes actions that may be taken in the agricultural sector to mitigate these impacts, such as diversification, development of irrigation infrastructure, and reforestation (BNRCC, 2011). The Building Nigeria's Response to Climate Change (BNRCC) plan is considered exemplary among national adaptation plans, yet it offers little practical guidance to communities and stakeholders engaged in poultry farming; most of the document's emphasis in the livestock sector is on cattle. We argue that participatory systems research that engages poultry sector stakeholders in dialog and in learning from one another is needed to create the details and incorporate the complex context needed to implement Nigeria's climate change adaptation plan for the poultry sector effectively. Our approach uses participatory system dynamics modelling.

System dynamics modelling (SD) is a technique that has been used since the 1960s to investigate solutions to complex problems over time (Sterman, 2001). It has been applied in fields as diverse as business management, health, international relations, natural resource management, and urban planning. An SD model consists of a series of differential equations depicting relations between variables, and the output is calculated in sequential time steps. These models are useful for their predictive capability, allowing users to ask 'what if' questions about the behaviour of a system, and to test dynamic hypotheses (Stave, 2002). They are capable of synthesizing multiple types of information, including qualitative and quantitative data, and represent causal structures and feedback loops that are difficult to depict in more traditional statistical models. Participatory system dynamics modelling entails constructing, parameterizing, running, and validating the model as a collaborative effort between modellers and stakeholders, although the nature of this collaboration may vary depending on the context of the modelling project (Hovmand, 2014; Van den Belt, 2004; Voinov & Bousquet, 2010). Building a model together with stakeholders is an opportunity to foster a mediated discussion using a systems approach (Vennix, 1996). Because of the large variation in participatory modelling (PM) projects, and the need for more standardized reporting on these projects to facilitate learning and advancement in the field, researchers have advocated for a '4P framework' (Gray et al., 2018) which reports on the purpose, process, partnerships, and products for a given PM exercise. We adopt that framework for this paper and use it to report on the methodological approach, and on the conclusions for policy, science, and modelling drawn from this project.

The objectives of this research and the **purpose** of the participatory modelling project were: (1) to give poultry sector stakeholders and policy-makers in Nigeria a modelling tool that harnesses their own in-depth knowledge of the sector and other published information in order to inform climate change adaptation and build resilience of livelihood systems; and (2) to facilitate collaboration and social learning around climate change adaptation among stakeholders at various nodes along the poultry value chain. The goal of the stakeholder engagement was to further increase their wealth of knowledge by discussing cross-cutting issues in two different regions of Nigeria with different climatic challenges to the poultry sector, thereby informing national and regional climate change adaptation plans in Nigeria.

Methods

In the context of this project, we decided on a system dynamics framework to capture the complex inter-dependencies between economic dynamics of the poultry sector, as well as climate and trade policy impacts on the sector over time. The participatory modelling **process** consisted of three workshops over the course of approximately 9 months, with model construction happening primarily between workshops 2 and 3. In addition to the material from the workshops, we drew on published literature and publicly available data to construct the system dynamics model. The first two workshops took place in Abeokuta in southern Nigeria, and Kaduna in northern Nigeria, in October 2017 and January 2018, respectively (Figure 1). Abeokuta is located in the Guinean climatic zone and receives an average of 1200 mm of precipitation annually. Kaduna is located in the Sahelian zone and has a similar precipitation pattern to Abeokuta, but higher average temperatures, making water stress a more significant issue.

The workshops were identical in format and were designed to provide inputs to the model construction process, as well as an introduction to general trends and challenges in the poultry sector. At the final workshop in June 2018, which was held in Lagos, the system dynamics model was presented for participant feedback, and scenarios of the Nigerian poultry sector were explored.

An agenda for the Abeokuta and Kaduna workshops is included in the supplemental materials for this manuscript (see Supplemental Material). The main outputs from these workshops were graphs over time of key variables related to the Nigerian poultry sector; causal loop diagrams depicting the relations between variables

Figure 1. Map of Nigeria with the locations of the two stakeholder workshops labelled. Abeokuta is in the south and Kaduna is in the north of the country.

affecting the Nigerian poultry sector; and a list of potential policy options and adaptation strategies to explore as scenarios in the model.

Stakeholder selection and invitation (PM partners)

Participants from different nodes along the poultry value chain were selected from the two locations bearing in mind their relevance and contributions to the poultry industry. They included researchers working on climate change and agriculture; policy makers (for example, the special adviser to the state government on agriculture and directors of livestock services); poultry farmers and retailers (small-scale and large scale); maize farmers; veterinarians and other input suppliers. These were important stakeholders with significant roles in the sector.

Causal loop diagramming

Participants were first divided into groups according to their position within the poultry sector (e.g. producers, feed millers, researchers, etc.) and directed through an exercise in which they drew graphs of key variables they identified as being important in the poultry sector over time, depicting how the Nigerian poultry sector would change up to the year 2060. Participants then described and explained these graphs, which were collected and used to construct a reference mode for the system dynamics model (Hovmand, 2014). For the causal loop diagramming (CLD) exercise, participants were assigned to groups of five with mixed representation from different 'nodes' of the poultry sector. Each small group had the opportunity to explain their diagram, and clarification questions were asked around variable names and relations. The CLDs were collected as input for the system dynamics model. We also administered surveys before and after each workshop in Abeokuta and Kaduna, to assess participants' perceptions of the poultry sector and shifts in systems thinking in response to the workshops. A full analysis of the survey results will be shared in a future paper, but we include some of the descriptive characteristics here.

After the second workshop, the CLDs were analyzed for (1) feedback loops; (2) drivers of poultry sector growth; and (3) climate impacts. These three factors were synthesized in the model structure across both workshops. During the workshops, participants had the opportunity to describe their CLD and the meaning of the variables and relations between them. Facilitators took notes on these descriptions to assist in sorting like variables (e.g. 'erratic temperature' and 'increased heat'). Contradictions between variable relations were brought up for discussion in the workshop for resolution (e.g. if one diagram indicated a positive relationship and another an inverse relationship between variables). In addition, variables that were considered too vague to interpret (e.g. 'government policies') were noted as items for discussion in the final workshop. Variables considered to be outside of the system boundary, with the system being poultry sector in Nigeria, were removed and incorporated into the model runs as scenarios; examples of such variables include climate variables (extreme heat and precipitation).

The model simulates the stock of poultry products in Nigeria as a function of internal production, imports, consumption, and mortality (Figure 2), following the logic described by workshop participants in the CLDs (Figure 3). Production is driven by demand but restricted by trade policy and the price and availability of feed. The full model structure, parameters and equations are included in the supplemental material.

Climate change was incorporated into the model in several ways. Previous work under the Nigeria Agricultural Policy Project, and other simulations of future crop yields in sub-Saharan Africa, have indicated that climate change could potentially erase all future gains in grain yield in West Africa (van Ittersum et al., 2016; Roudier et al., 2011). We therefore simulated the climate change impact on growth in maize yield, a key feedstock for the poultry sector, as reducing this gain in yield to zero. Of course, the actual impacts of climate change on grain yields are highly dependent on a number of complex interactive factors (land management, technology development, the ultimate severity of climate change, input and credit availability, etc.). So we used a scenario approach to the simulation to vary effects on maize yield and observed the output results. In addition, climate change was expected to increase the frequency of poultry die-off events caused by extreme heat and by disease (Rosenzweig et al., 2001). There is no data currently available on the total impacts of heat and disease deaths on the Nigerian poultry sector, so we parameterized these impacts through consultation with the stakeholders, again using scenarios and sensitivity analysis to accommodate

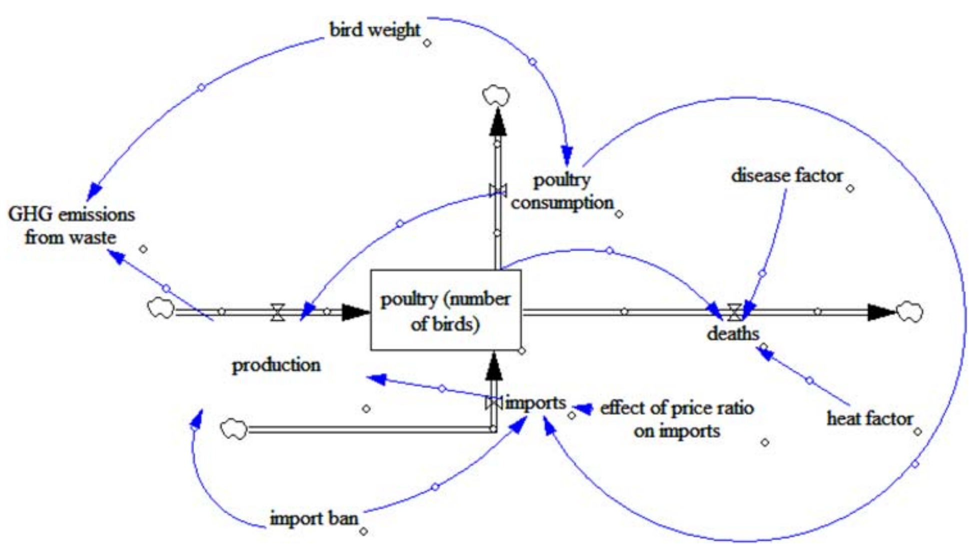

Figure 2. Basic model structure for simulation. Poultry stock in Nigeria is a function of poultry production, deaths, imports, and consumption. Consumption in the model is driven by consumer demand.

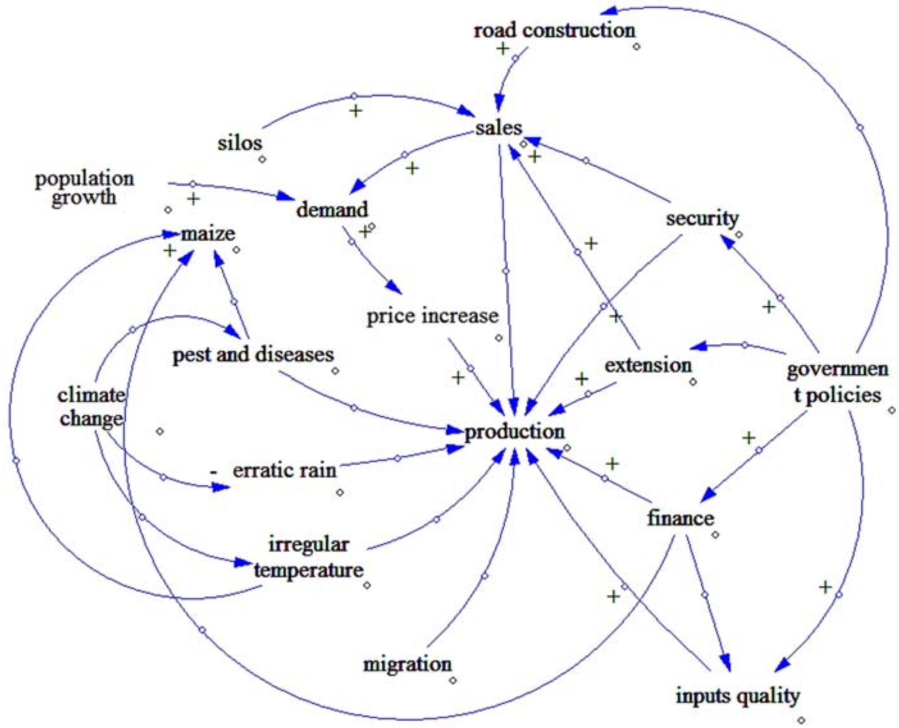

Figure 3. Example of a causal loop diagram generated by poultry sector stakeholders in Nigeria in response to the question, 'What will affect poultry production in Nigeria up to the year 2060'?

the high uncertainty involved in these parameter estimates, as recommended by system dynamics modelling best practices (Hekimoglu & Barlas, 2010).

In addition to CLD construction during the first two workshops, participants discussed potential scenarios for model simulation. The discussion was framed around policy interventions or external factors that could impact the poultry sector over the short term (5 years) and long term (20+ years). Based on the notes taken during this discussion, several scenarios were chosen for simulation (Table 1). An individual sensitivity analysis was conducted on all model input parameters to investigate the sensitivity of poultry production and mortality to input parameter variability of ±10%.

The final stakeholder workshop in Lagos, Nigeria took place in June 2018. Invited participants were selected from the previous two workshops to represent both regions (North and South) of the country, and the diverse nodes of the poultry sector. We also attempted to create gender balance in the final workshop invitations, as well as a balance between large- and small-scale poultry farmers, and stakeholders with formal education versus practical experience. Given these parameters, we constructed an invitee list of 40 people, approximately

Table 1. Potential scenarios for model simulation.

Scenario	Description
Baseline	'Business as usual' simulation of current trends in the poultry sector
Disease	Every 20 years on average, a disease event kills 40% of the poultry stock
Climate change	Every 5 years on average, a heat event kills 5% of the poultry stock. In addition, maize yield is suppressed by 25%.
No import ban	Import restrictions are lifted, resulting in potentially unlimited imports of poultry contingent on price
Lower price of imports	Imported poultry are 20% less expensive than domestic
Highest price of imports	Imports are twice as expensive as domestic poultry
SA consumption	Nigeria achieves South African levels of per capita poultry consumption by 2060
Increase in wealth	Poultry consumption grows by 20% by 2060

half of the attendees of from each of the Abeokuta and Kaduna workshops, respectively. All travel, lodging, and per diem expenses for all participants in each of the three workshops were paid for by the project.

The final Lagos workshop included three main activities: (1) a demonstration and discussion of the model structure and behaviour, focusing on eliciting participant feedback on missing variables, unreasonable behaviour, and potential interventions; and (2) targeted feedback on model relations and parameters which were challenging for the modelling team to represent in the simulation, due to missing data or conflicting information; and (3) a group discussion around poultry sector adaptation strategies. Detailed notes were taken throughout each session by at least two note-takers per session.

Results

Thirty seven (37) participants attended the Abeokuta workshop (26 men and 11 women). The level of formal training was weighted toward post graduate degree training (just under sixty-eight percent of the respondents), with approximately twenty-four percent earning a master's degree and twenty-two percent earning a doctoral degree. The majority of the participants were involved in the poultry business for over 10 years (approximately sixty-seven percent); the majority were thus farmers, worked in poultry training or extension, or product sales and marketing.

The Kaduna workshop was similar, with thirty-seven (37) participants (21 men and 16 women). The level of formal training was weighted toward post graduate degree training (just under fifty percent of the respondents), with respondents with some college training adding another fourteen percent. The majority of the respondents were involved in the poultry business for over 10 years (over forty percent of the respondents). The majority of the respondents were farmers, worked in poultry training or extension, or product sales and marketing. The Kaduna workshop participants were therefore, on average, less formally educated and less experienced than the Abeokuta workshop participants.

Figure 4 depicts the model output under the different scenarios of poultry production described above. According to the model logic, climate change impacts poultry supply negatively through heat mortality,

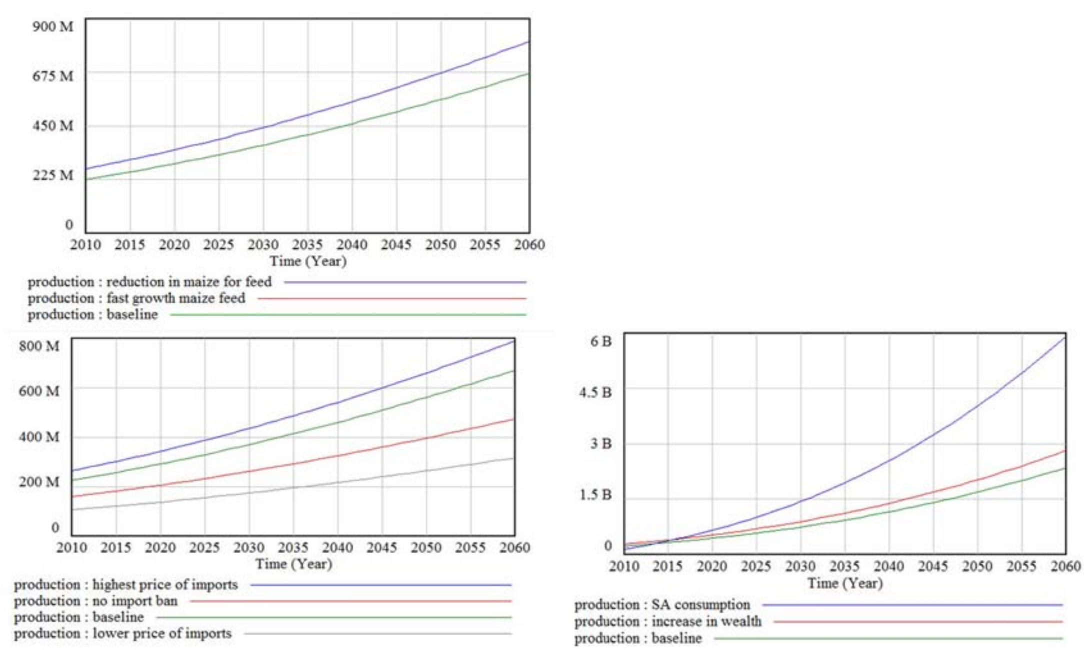

Figure 4. Production of poultry in Nigeria under various scenarios between 2010 and 2050. Baseline (business as usual) scenario is in green in each panel. Detailed scenario descriptions are in Table 1. Clockwise from top left, the panels depict feed scenarios; import policy scenarios; and economic scenarios as detailed in the text.

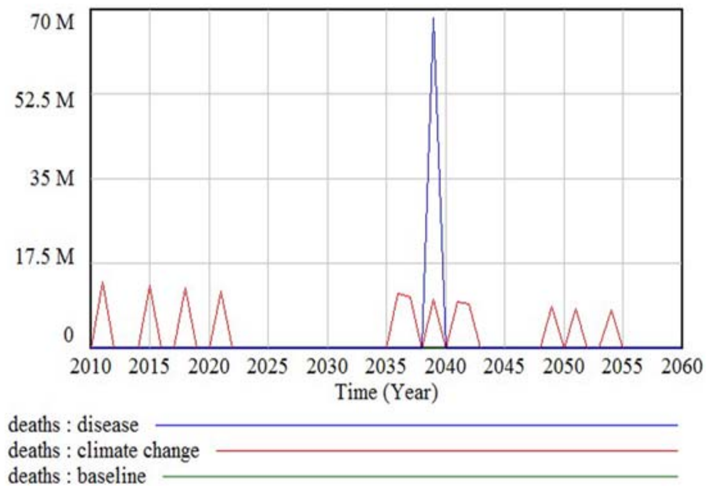

Figure 5. Modelled poultry deaths in Nigeria under climate change and disease scenarios between 2010 and 2050.

disease events, and lower maize yields. While production of poultry is the same under climate change, poultry mortality is higher due to heat events, reducing overall poultry supply (Figure 5). It is important to emphasize that this production is estimated for the poultry sector as a whole. Individual producers would certainly be adversely impacted by increased mortality, and could go out of business. However, these intra-sector dynamics are not captured in the model. Small-scale farmers may be hardest hit by losses from heat, according to workshop participants.

Maize is the dominant ingredient in poultry feed in Nigeria, and the model demonstrates that if 30% of the maize feed supply is replaced with cassava, poultry production in Nigeria could increase, indicating that the availability of maize feed is a limiting factor in the Nigerian poultry sector (Figure 4). Import policy has an expected effect on poultry production, with the model demonstrating increased production when imports are expensive, and decreased production when they are abundant (due to a relaxed ban) or inexpensive. Relative wealth of the population and consequent demand for poultry has a much larger impact on production than trade policy. Were Nigeria to attain South African levels of per capita poultry demand, poultry production could triple by 2060 (South Africa was chosen for comparison as an example of a wealthy African nation).

Upon interacting with the model, workshop participants provided feedback on a variety of dynamics and factors which were not included in the model, but which they felt to be potentially significant to the future of the poultry sector. These included a more nuanced grasp of specific diseases of concern for poultry, and their dynamics. Currently, the model simulates a disease epidemic of 40% mortality that occurs every 20 years on average (Figure 5). The discussion at the workshop revealed coccidiosis and Newcastle disease, as well as toxins in feed, to be key diseases of concern in the poultry sector. Each of these diseases would be affected differently by increased temperatures and would have different effects on poultry. In addition, poultry production in Nigeria tends to be seasonal, in response to purchases for holiday feasts (for example, Christmas and Eid). This seasonality was not captured in the model. Land and water constraints on the poultry sector were also not included in the model but were discussed by workshop participants as becoming increasingly important, especially in more densely populated regions of the country. Finally, the high uncertainty involved in grain production and import policies was captured imperfectly in the model, but it was identified an important determinant of the future of poultry production in Nigeria.

Stakeholders suggested a range of climate change adaptation strategies, which, following the final workshop, were included in a pamphlet produced for distribution to Nigerian extension services (Appendix 1). In particular, at the final workshop, strategies for reducing heat impacts on poultry were discussed, including improving ventilation of poultry shelters; choosing poultry stock indigenous to West Africa that can better withstand heat; and planting shade trees around poultry shelters. Strategies for resilience to disease outbreaks

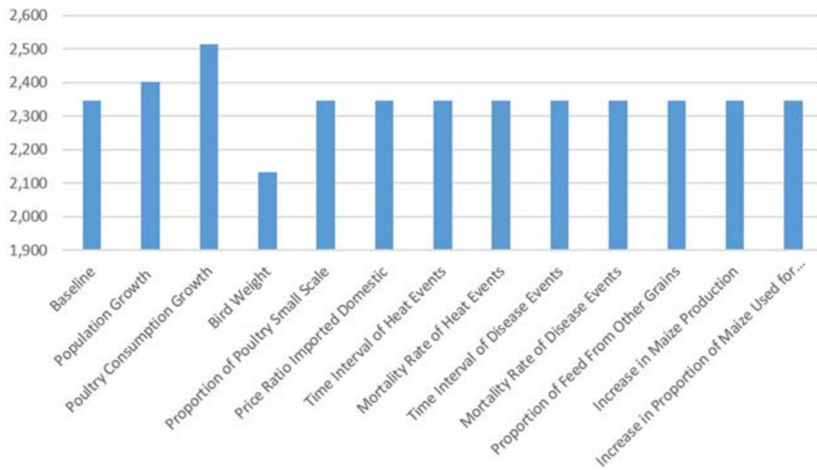

Figure 6. Individual sensitivity analysis representing the effects of input parameters on production when increased by a factor of 10%. Poultry production in the model is most sensitive to poultry consumption factor and poultry weight.

included vaccinations and using best practices for stocking densities, while alternative feeds, including cassava, were discussed as strategies for resilience to feed supply chain interruptions.

Poultry production as represented in the model is most sensitive to poultry weight (which in turn is dependent on breed of poultry, feed and growing conditions) and rate of poultry consumption. Poultry production is moderately sensitive to Nigerian population growth and relatively insensitive to other input factors (Figure 6).

Discussion

The **products** of this participatory modelling exercise included a system dynamics model depicting the future of the poultry sector in Nigeria under climate change, demographic and economic change; and preparation of a pamphlet on best climate change adaptation practices for poultry producers, which was translated into Yoruba, Hausa and Igbo (the three most commonly spoken Nigerian languages) and distributed through the networks of workshop participants. The model was anticipated to be a product from the project conceptualization stage, while the pamphlet came about when workshop participants decided to self-organize to summarize and distribute the learning outcomes from the workshop. It thus became a key output of the research project. The policy insights from the process were disseminated from 'bottom to top' through the workshop participants with connections to state and local policy-making (for example, the special advisor to the state government), and from 'top to bottom' through discussions about how to implement the federal recommendations around climate change adaptation in the livestock sector, given local context.

The first purpose of this participatory modelling project was to give poultry sector stakeholders and policymakers a modelling tool to inform climate change adaptation and build resilience of livelihood systems. This purpose was partly fulfilled. As evidenced both by the model output and the discussions during the final workshop, Nigeria's poultry sector is largely dominated by national and international drivers outside of the immediate control of the workshop participants. These include trade policy for imported chicken (whether it is banned, restricted, or has tariffs imposed); the relative future wealth of the Nigerian population and their demand and preferences for poultry over other animal proteins such as fish and beef; consumer preference for local versus imported poultry products; and climate change. A scenario-based approach which embraces the large uncertainty in poultry sector development, rather than a predictive use of the model, is therefore a more appropriate tool for planning at sub-national scales (Swart et al., 2004). Nevertheless, the model is useful as a tool to facilitate discussion around *adaptation* strategies in light of these large-scale drivers and uncertainties, where results can be used to inform policy from the federal to the household level. The model output demonstrates these large-scale uncertainties quantitatively, such that the workshop discussion focused on how producers and poultry sector stakeholders could cope with the risks associated with these uncertainties. A range of climate change adaptation strategies at the producer level were discussed, resulting in the pamphlet described above (Appendix 1). These strategies mainly deal with protecting poultry from heat (elevated and sustained temperature rise) and disease events. Workshop participants also discussed producers growing their own feed as a strategy for dealing with the rising costs of feed and using cassava-based feed rather than maize-based feed, as cassava is a more climate resilient crop (Jarvis et al., 2012).

Given the significant impact of trade policy on the poultry sector, workshop participants emphasized the need to organize and inform policy-makers at the national level about adverse impacts of their policies on the ability of the poultry sector to adapt to climate change. For example, participants felt that a ban on imported poultry current at the time of the workshops had led to black market trade which was undermining local poultry sales, although the evidence for this is inconclusive (Ogunleye et al., 2016). In addition, workshop participants discussed the need to educate Nigerian consumers about the quality of locally produced poultry and the value of knowing where food comes from, echoing the local food movement arguments prevalent in Western industrialized food systems.

In spite of the multiple challenges faced by the Nigerian poultry sector, all of the 'graphs over time' exercises completed by stakeholders at the first two workshops depicted the poultry sector growing over the next 40 years. The model output concurs, representing poultry production growth in all scenarios; the rate of growth, however, varies widely according to the drivers discussed above, as do poultry mortality rates. This reflects the rapid growth in food demand in Nigeria generally. Given the country's large population and high population growth rates, combined with urbanization and a growing middle class demanding meat, it is implausible that the poultry sector would not grow to meet at least part of this demand, barring a catastrophic failure. This makes the discussion around resilient and sustainable growth of poultry production all the more important.

The second purpose of this participatory modelling project was to facilitate collaboration and social learning among stakeholders at various nodes along the poultry value chain and from different perspectives. Given the engaged discussions about adaptation strategies and policy in all three workshops, and the stakeholder-organized production of the pamphlet for distribution to poultry producers, we would argue this purpose was fulfilled. Other evidence of learning is shown in the survey results from the Abeokuta and Kaduna workshops. Participants in both workshops reported an increase in systems thinking (from a mean of 3.67 to a mean of 4.41 on a 5-point Likert scale in Abeokuta; and from a mean of 4.22 to a mean of 4.27 in Kaduna), and expressed more awareness of climate change and the environmental impacts of the poultry sector post-workshop.

Prior research has shown that sharing and learning through social networks is critical for policy uptake by local communities (Cunningham et al., 2016). In the workshops, discussions around the federal climate change adaptation recommendations included how tree-planting activities could provide optimal shade for livestock, and how the livestock recommendations in the adaptation plan could be adapted for the poultry sector. It was clear from the discussions that this was the first time many workshop participants were given the opportunity to think about the poultry sector as a system, and to exchange ideas and observations with stakeholders sitting at different positions within the sector. In some cases, this led to tense disagreements. For example, at the Kaduna workshop, poultry producers and poultry buyers had a heated exchange around bird mortality and payment schedules, with each accusing the other of unfair practices. Through mediation by the facilitators, the conversation was re-directed to the overall problem of lack of credit availability in the sector, which exposes both producers and buyers to risk.

The modelling process was limited in several ways. While we made an effort to include poultry sector stakeholders that represented as many aspects of the poultry value chain as possible, there were some notable omissions. For example, there were no consumer advocates at the workshops (although nearly all of the participants, in addition to their formal roles, were consumers of poultry products). This may have resulted in a model of poultry consumption that was simplistic compared with the supply side of the sector. In addition, the modelling process was constrained by the time frame for the project; ideally, there would have been an opportunity for the modellers to incorporate the feedback from workshop participants and develop an updated draft of the model for presentation to the stakeholders. This could have improved the usefulness of the model, and participant trust in the model. This participatory modelling process is time-consuming and expensive (due to the expense of gathering multiple people from across the country together). It may therefore not be feasible in a project that is significantly constrained by lack of time or funding.

The results of this research will be integrated into other climate change adaptation work that is ongoing in Nigeria (cf [Olabisi et al., 2018]), and we plan to use the results of the surveys administered to participants at the Kaduna and Lagos workshops to analyze shifts in systems thinking that took place as a result of interacting with the model and with fellow workshop participants.

Conclusions

The dual **purposes** of this participatory modelling project were, first, to give poultry sector stakeholders and policy-makers in Nigeria a modelling tool that harnesses their own in-depth knowledge of the sector and other published information in order to inform climate change adaptation and build resilience of livelihood systems; and, second, to facilitate collaboration and social learning around climate change adaptation among stakeholders at various nodes along the poultry value chain. Given the high uncertainty of the conditions under which the Nigerian poultry sector will develop, we see the model's use primarily as a discussion tool for poultry sector stakeholders to share concerns and adaptation strategies. Evolution of the poultry sector in Nigeria is influenced by a number of large-scale forces, including the economic conditions of the country, import policy, and climate change. However, stakeholders have already implemented a variety of climate adaptation strategies. Notably they are adapting federal recommendations to a local context, and most stakeholders remain optimistic about the future of the poultry sector. Besides the model itself, a **product** of the modelling process was a pamphlet detailing strategies to guide poultry sector adaptation to climate change. The participatory system dynamics modelling process was effective to encourage social learning, knowledge production, and implementation of federal policy recommendations in a local context.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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