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How to enhance the sustainability and inclusiveness of smallholder aquaculture production systems in Zambia?

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ABSTRACT

Fish is a key source of income, food, and nutrition in Zambia, although unlike in the past, capture fisheries no longer meet the national demand for fish. Supply shortfalls created an opportunity to develop the aquaculture sector in Zambia, which is now one of the largest producers of farmed fish (Tilapia spp.) on the continent. In its present form, the aquaculture sector exhibits a dichotomy. It comprises, on the one hand, a smallholder sector that mainly produces for and supplies within local markets, and on the other hand, a burgeoning larger-scale commercial sector consisting of a small number of pioneering lead firms who are (re)shaping how the value chain supplies domestic, mainly urban, markets. A notable challenge confronting the development of the aquaculture value chain in Zambia is ensuring that the larger-scale commercial sector can continue to grow and generate economic benefits for the country, while simultaneously safeguarding inclusive and sustainable growth of smallholder production systems. An in-depth, mixed-methods aquaculture value chain study was carried out in Zambia in 2017 that aimed at providing relevant stakeholders with pertinent information on the value chain's contribution to economic growth and its inclusiveness, as well as its social and environmental sustainability aspects. In this article, we present some key findings from the study to shed light on how the sustainability of smallholder production systems could be enhanced while preserving the growth trend of larger producers in an inclusive way. The study found that the value chain is contributing positively towards economic growth in the country. Smallholder farmers classified as "semi-subsistence" and "commercial" face several albeit somewhat different constraints to production, thus influencing their "sustainability" status. Semi-subsistence smallholders achieve positive (yet negligible) profit margins, and their production system is not environmentally sustainable and the value chain that supports them performs sub-optimally on several social markers. The "commercial" smallholder system is more economically viable and environmentally sustainable. The study juxtaposes these findings with those from the analysis of larger pond and cage-based systems to point to a set of key options Government, research, and development organisations could consider to support smallholder farmers and enhance the sustainability of the semi-subsistence smallholder production system in particular, without overlooking the whole system.

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1. Introduction

1.1. Sustainability and inclusiveness in Agri-food value chains

Sustainability and inclusiveness are at the top of many international political agendas, and policymakers are asked to report progress against such priorities —e.g., see the Comprehensive Africa Agriculture Development Program – CAADP (https://au.int/en/agenda2063/) or the UN 2030 Agenda for Sustainable Development and the Sustainable Development Goals (https://sdgs.un.org/goals). Both the CAADP and the European Commission proposal for a New European Consensus on Development (Faure and Maxwell, 2017) identify inclusive and sustainable growth and jobs as an overarching priority. In this context, sustainable agriculture, together with fisheries and aquaculture, remain key drivers for poverty eradication and sustainable development. The attention to an increase in agricultural production has now been coupled with a stronger focus on social and environmental sustainability. Moreover, value chains are recognised as major channels for agricultural development due to their capacities to mobilise resources from various economic sectors, create economic value and generate employment (Haggblade and Theriault, 2012; Reardon et al., 2018). This requires an understanding of not only the economic performance of agri-food value chains, but also of their social and environmental impacts to shed light on sustainability from a broader perspective (Dabat et al., 2018).

Whether value chains are "sustainable" and "inclusive" in the context of this article is understood as the degree to which they provide resource-poor actors with equitable economic and social benefits, without putting excessive pressure on the environment (Kaminski et al., 2020). Risks for the inclusiveness of value chain development have been summarised by Ros-Tonen et al. (2019) as value chains aggravating existing inequalities and excluding marginalised people. Such "adverse inclusion", i.e. participation under disadvantageous conditions with inequitable sharing of benefits and risks, may occur when vulnerable value chain actors have limited agency and power, and access to and control over assets. In addition, women and vulnerable groups may not be able to benefit fully from value chains due to gender inequalities in formal institutions and harmful norms and attitudes (Kruijssen et al., 2018b). Value chains may also have a myriad of potential negative environmental impacts, which may differ according to production practices (FAO, 2014a; Sala et al., 2017).

Value chain investments are thus not inherently pro-poor, or environmentally sustainable. Moreover, the three dimensions of sustainability may at times be at odds, and require trade-offs (under a weak-sustainability perspective (Garmendia et al., 2010)). While there is recognition of the importance of considering the "triple bottom line" in value chain analysis, those studies that provide sufficient evidence to take informed decisions on all three dimensions are scarce (Bolwig et al., 2010). In addition, value chain analyses have been criticised for not providing sufficient quantitative information (Raikes et al., 2000), or only on indicators relating to a particular firm, without providing indicators for the performance of the entire chain. Making informed investment decisions without such information, becomes difficult, and could even lead to unintended negative consequences (Rich et al., 2011).

This article therefore aims to contribute to filling this information gap. It does so by providing a case study of the application of a value chain sustainability assessment methodology to the Zambian aquaculture sector. The methodology brings together several analyses and provides quantified indicators across all dimensions of sustainability. The article proceeds as follows. Section 1.1 provides a theoretical framework for the paper and reviews a selected literature on sustainability and inclusiveness in value chains, while Section 1.2 introduces the Zambian aquaculture sector. Section 2 describes the methodology used for the value chain analysis. Section 3 presents the results, starting with a functional analysis of the value chain, followed by an assessment of the value chain from the three sustainability perspectives. Section 4 discusses implications of the results for enhancing the sustainability of smallholder production systems and for achieving inclusive value chain development. The last section presents key conclusions.

We use the term "value chain" in a practical and operational sense to inform decision-makers (EC, 2014), instead of as a theoretical device.[3] We position this article in the context of the debate on the "triple bottom line" (i.e. economic, social and environmental sustainability) (JRC, 2012), rather than the global value chain literature that focuses on "governance" and "upgrading" in value chains (Gereffi et al., 2005).

1.2. The Zambian aquaculture sector

While the global population grows, and income levels increase, people are consuming more meat and fish (OECD/FAO, 2018). As most wild fish stocks are fully- or over-exploited (FAO, 2018a, 2020), and fisheries are increasingly affected by climate change (Bertrand et al., 2020; FAO, 2018), there is a widespread opinion that the greater demand for fish can only be fulfilled by aquaculture. Aquaculture is thus key to delivering both proteins and micronutrients, especially in low-income countries such as Zambia (Longley et al., 2014). Moreover, it is an economic activity with the potential to be as important as agriculture for smallholder producers, in terms of socio-economic development and food security (Bondad-Reantaso and Prein, 2009; Kaminski et al., 2020; Toufique and Belton, 2014).

Zambia is a landlocked country in the southeast of Africa, endowed with lakes, rivers, wetlands and seasonal floodplains. Fish from the capture fisheries in the country is often the only accessible and/or affordable source of animal protein for resource-poor populations in rural areas, and provides 55% of the animal protein in Zambian diets (Longley et al., 2014; NFDS Africa, 2016). In 2016, the annual per capita fish intake was 14.5 kg, below the world's average of 19.2 kg/year, but above the sub-Saharan Africa average of 8.9 kg/year (FAO, 2016). Imported fish represented 52% of the national fish supply in 2016, while the rest was mainly supplied by capture fisheries and at a lesser extent aquaculture (Department of Fisheries, 2017). National aquaculture production represented less than 13% of the total fish supply in 2016 (Department of Fisheries, 2017), despite recent growth in domestic production (mainly tilapia species, *Oreochromis* spp.), making Zambia the sixth-largest producer of farmed fish in Africa (Kaminski et al., 2018). With capture fisheries likely to remain stagnant or even decline in their production in the coming years due to the use of unsustainable fishing practices (Cole et al., 2018), and with the desire to curb imports of fish into the country (AfDB, 2016), aquaculture production is becoming increasingly important to supply the Zambian population with fish for consumption (see also http://www.daily-mail.co.zm/fish-imports-must-end-says-lungu/).

The aquaculture sector in Zambia exhibits a dichotomy between a smallholder producer and distribution sectors and an expanding larger-scale, vertically integrated commercial sector. In the former, in spite of support provided by government and non-government initiatives, smallholder farmers have little access to services, inputs and markets and consequently do not seem to grow (Harrison, 1996; Kaminski et al., 2018). The latter is dominated by a few pioneering, fast growing lead firms who have reshaped the commercial value chain and dominate domestic production and distribution (Kaminski et al., 2018).

Presently, over three quarters of domestic aquaculture production comes from large-scale cage culture firms operating on Lake Kariba and from large-scale pond-based firms around Zambia's capital Lusaka. Large-scale firms accounted for only 25% of total production a decade ago (Department of Fisheries, 2017). These types of systems are represented by a limited number of producers, while the vast majority of aquaculture producers in the country exploit small-scale, pond-based systems spread all over the national territory but mainly in the northern

[3] The term "value chain" refers to the network of actors and their activities delivering a product or service (sometimes referred to as a "supply chain").

parts of the country (Department of Fisheries, 2015) and predominantly in rural areas (Genschick et al., 2017b; Kruijssen et al., 2018a), with adequate access to water.

The smallholder sector is characterised by a large population of 9 615 fish farming households in 2018 (Ministry of Fisheries and Livestock, 2019), from around 12 000 in 2015 (Department of Fisheries, 2016), and very low individual and overall production (Kruijssen et al., 2018a). There is a strong interest by the Zambian government and by many international development-funding institutions to improve the socio-economic performance of smallholder aquaculture producers, to alleviate poverty. In this article we emphasise that any improvement targeting one actor category or one dimension of sustainability would not be sufficient, if it does not also contribute to sustainable and inclusive growth of the whole aquaculture value chain. In other words, sustainable and inclusive growth implies the diversification of objectives/strategies of stakeholders: not only to support specific categories of actors, but enhance the performance of the whole system (Haggblade and Theriault, 2012; Kaminski et al., 2020). It would be characterised by improved performance across the three classical interlinked dimensions of sustainability: social (e.g. better inclusion of marginalised groups in production), economic (e.g. higher yields and income, better market access, more jobs), and environmental (e.g. limiting environmental impacts, especially where they are largest).

The challenge confronting the development of the aquaculture value chain in Zambia is therefore to ensure that the larger-scale commercial sector can continue to grow and generate economic benefits for the country, while also ensuring inclusive and sustainable growth of smallholder production systems. To inform the development of sound policy and investment options, Government and development actors require accurate data to base decisions on. Such data are however presently lacking on the Zambian aquaculture sector. This article presents these data and suggests possible policy and development options based on the evidence.

2. Methodology

This article is based on the results of a research project funded by the European Commission (VCA4D - Value Chain Analysis for Development 2016–2022, https://europa.eu/capacity4dev/value-chain-analysis-for-development-vca4d-), part of the European Union's "Inclusive and Sustainable Value Chains and Food Fortification Programme". VCA4D is a partnership between the European Commission and Agrinatura (https://agrinatura-eu.eu/), the alliance of European universities working together for agricultural research and education for development.

The methodological framework of VCA4D is structured around the need for evidence-based knowledge to orientate policy makers' investments and improve and monitor the impacts and results of their policy interventions on value chains in terms of sustainability and inclusiveness. A toolkit was developed by policy makers to be implemented by scientists within a relatively short time frame, to identify at which stages of the value chain and for which actors investment and support can generate benefits, eliminate drawbacks and constraints and foster sustainability and inclusiveness. The analysis is conducted around four framing questions that provide policy makers with elements of information easily understandable and useful for decision making: What is the contribution of the value chain to economic growth? Is this economic growth inclusive? Is the value chain socially sustainable? Is the value chain environmentally sustainable?

The methodology aims at generating evidence, supported by a list of indicators quantitatively measured and/or based on expert assessments, which together provide an estimation of the contribution of the studied value chain to economic growth, its inclusiveness, as well as its social and environmental performance. The analytical process carried out during the Zambian aquaculture value chain analysis comprised four components, as follows.

A functional analysis was carried out first to produce a general mapping and description of the main stakeholders, activities, and operations in the value chain, an overview of the products and product flows, the major production system types, a description of the main governance mechanisms in the chain, and a short description of known constraints. The functional analysis formed the basis for the analyses in the other three components. A key outcome of this analysis was a typology of producers, as no formal classification of fish farms existed in Zambia as of 2018. The typology was built based on statistics and other data describing the level of technical intensity of different production systems (extensive-intensive continuum, as defined in Genschick et al. (2017b)), their degree of commercialisation (from farm-side sales to full vertical integration, as defined in Genschick et al., (2017b)), and the type of aquaculture system (ponds, cages, others). Technical intensity is usually correlated with capital, labour and management intensity in aquaculture (Oddsson, 2020). Discrete coherent classes were identified for these parameters to arrive at a comprehensive typology.

Economic, social and environmental analyses were subsequently performed. The economic analysis investigated the finances of each type of stakeholder, assessed the overall value chain, and estimated the inclusiveness of economic growth by examining income distribution and employment creation and distribution. Based on the financial analysis and the estimates for the contribution of each actor in terms of overall volume, the contributions of each actor type to total value added (i.e. the sum of salaries, taxes, financial charges, depreciation and net operating surplus, aggregated across all actors) of the value chain, net operating surplus, and wages were calculated. By examining the data at the micro and macro-levels, conclusions about the economic viability and inclusiveness of the value chain were extracted.

The social analysis explored social sustainability, including inclusiveness of economic growth. The social domain of the aquaculture value chain was analysed through many layers of people's life and livelihoods. The framework used paints a picture or snapshot of the main outcomes of the value chain activities in six basic domains: working conditions, land and water rights, gender and social inclusion, food and nutrition, social capital, and living conditions. It drew on multiple information sources, including secondary and field data from aquaculture producers at different scales, hatchery owners, processors, input suppliers, traders, and other government and non-government stakeholders.

The environmental analysis used Life Cycle Assessment (LCA) to estimate environmental impacts, across a large variety of impact categories, of each type of stakeholder in the value chain. The calculation of relevant environmental indicators was based on an inventory of all input and output fluxes over the entire life cycle of the studied systems, mainly relying on field-collected primary data and complemented with secondary data (scientific and grey literature). The environmental hotspots associated with each type of stakeholder were identified. Impacts are expressed as single scores, which represent a dimensionless aggregation of all impact categories.

All analyses were based on secondary data complemented by qualitative interviews and structured questionnaires with both stakeholders and experts in the aquaculture sector. Primary data were collected during two fieldwork stages (in February and May 2017), and through follow up with key respondents after the second stage. The functional analysis was carried out in the first stage mainly in and around Lusaka and in the Southern Province, where the larger producers are located. Interviews were carried out with government officials and other relevant stakeholders: fish, feed and seed producers; wholesalers, retailers and processors; financing institutions and non-governmental organisations. This stage also laid the foundation for in-depth data collection during the second stage relating to the economic, social and environmental analysis. The second stage mainly focused on collecting detailed data through a survey that combined questions of the economic and environmental analysis, while collection of data for the social analysis was conducted using both a structured questionnaire and focus group discussion guide. The second stage concentrated its focus more on smallholders and took place in Northern, Copperbelt, and Northwestern

Provinces. A total of 89 people were interviewed, covering a range of actors. During some of the producer interviews, and later via email, a representative dataset was developed that comprised primary economic and environmental data that were obtained from over 20 producers of all types, as well as feed producers, and commercial and government seed producers.

Finally, various options for action were formulated to address the challenges and issues found across the sustainability dimensions, which were consolidated into sustainable growth strategies aimed at the smallholder producer as the identified value chain actor and node requiring focused support. The application of the VCA4D methodology delivered curated information on major impacts of the value chain activities. Sometimes researchers worked with relevant hypotheses and provided orders of magnitude rather than precise figures, when unavailable, usually deemed sufficient for decision-making.

Data sources and methodological details of the functional, economic, social and environmental analyses are available in the Supplementary Material, and in higher detail in the official project report (Kruijssen et al., 2018a).

3. Results

3.1. Current status of the Zambian aquaculture value chain

The functional analysis was centered on the producers, thus a typology of producers was developed and the other value chain stakeholders were mapped around it. Five types of aquaculture systems were identified in Zambia, which can be differentiated based on the type of aquaculture system, the level of intensity of their production, and the degree of commercialisation of their operations (Fig. 1). Large, barely managed, pond systems, as well as very large stocked water bodies were also identified as distinct types, but excluded from our analyses due to data constraints (no sufficient data was available on those systems, no relevant fieldwork was conducted, and these systems' contribution to the whole production is marginal), despite such systems being often key for the subsistence of certain rural households. These two system types, when combined, account for <10% of total aquaculture production. We found no evidence of large land- or cage-based system producing any species other than *O. niloticus*, while medium-scale systems do produce other tilapia species. Regarding the volume of production of each type, we defined specific classes for this study. Developing this typology may also contribute to monitoring the sector.

The medium- and large-scale producers are characterised by adequate technical and business training, access to (mainly urban) markets including own distribution networks, hired labour, access to and consistent use of high-quality inputs such as feed and seed (imported *O. niloticus* strains such as the Thai Genetically Improved Farmed Tilapia - GIFT), and access to financing. They engage in good management practices, including record keeping and tracking of their feed conversion ratios (FCR). Among the large producers, cage systems in particular were observed to be highly capital intensive.

The vast majority of smallholders operate at a level of efficiency that can be labelled as "semi-subsistence". In this system, aquaculture is performed as a secondary or tertiary activity, employing extensive production practices consisting of a few ponds, and deploying family labour. Producers use recycled local seed (some use *O. niloticus*), do not use commercial feeds but fertilisation (e.g. manure, kitchen wastes) and homemade feeds (agricultural by-products such as maize bran), culture fish for mainly self-sufficiency purposes rather than as a commercial enterprise, do not keep records or monitor their fish growth, practice

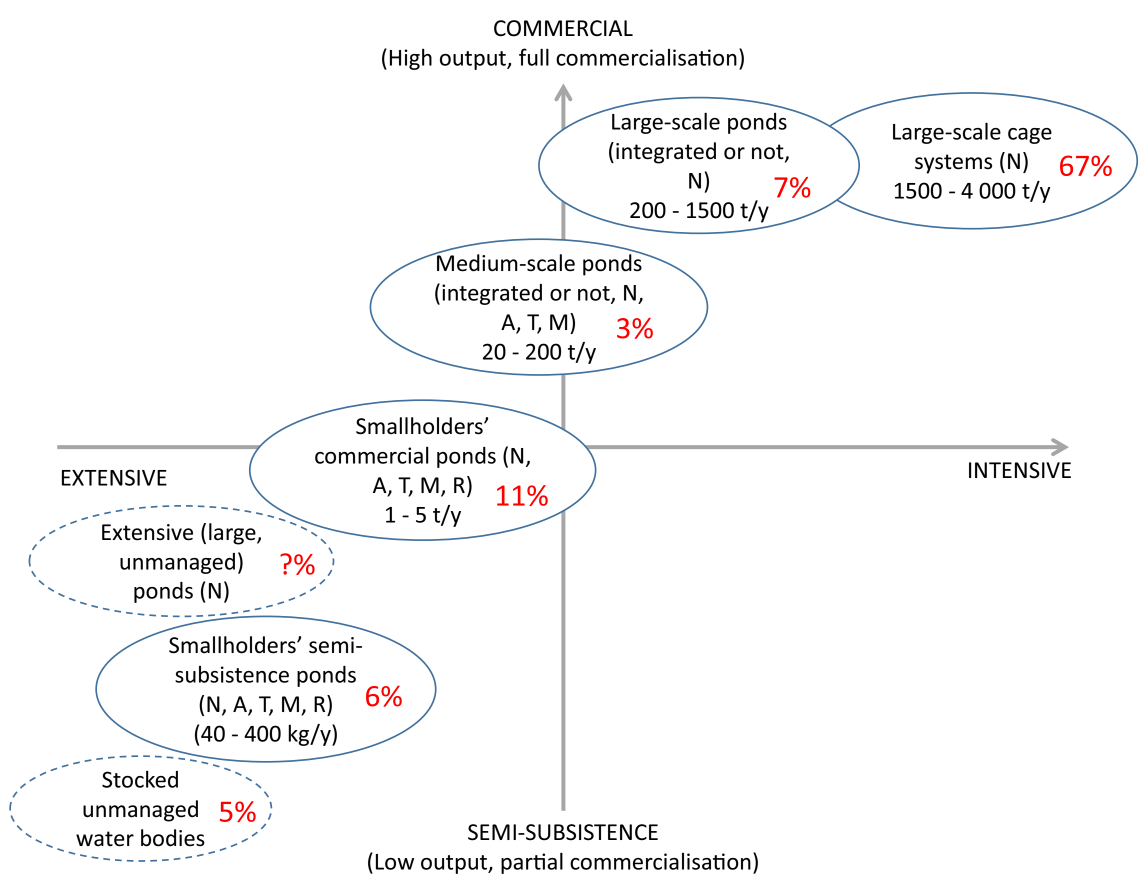

Fig. 1. Typology of Zambian aquaculture production systems. Legend: N = *Oreochromis niloticus*, A = *O. andersonii*, M = *O. macrochir*, T = *O. tanganicae*, R = *Coptodon rendalli*. Percentages represent the share in domestic production in, 2015–2016.

partial harvesting, and as a result, produce a smaller-sized fish.

A small proportion of the smallholder systems (Table 1), those referred to as “commercial”, are characterised by semi-intensive production and in most cases the farmers running them possess a higher level of skill than the semi-subsistence smallholders. These producers consider fish farming as a profitable activity and invest more in terms of inputs and labour. They use some commercial feeds, seed purchased from a hatchery, and have more aquaculture assets (e.g. nets for harvesting) and operate in clearer production cycles producing larger fish for urban markets. These producers have access to loans, if required. The majority of their harvested fish is sold rather than consumed in the household. They are generally better off than the semi-subsistence producers, in terms of their levels of formal education and their ability to invest in their fish farming business. These producers have better market linkages, although they also sell at farm gate. A portion have their own outlets, or relationships with restaurants and institutional buyers. They hire some labour for their activities.

The majority of smallholders (when not categorised, the term “smallholders” refers to both semi-subsistence and commercial farmers) in Zambia are found in the northern provinces (Muchinga, Northern, Northwestern, and Copperbelt) (Fig. 2), while the largest producers are located in the central and southern areas of Zambia. More recent statistical data suggests a reduction in the number of smallholders across the country (Ministry of Fisheries and Livestock, 2019).

Some medium-scale producers are also found in the northern parts of the country. Fingerling production in the north is still mainly government-driven although some private hatcheries are found in Northern and Copperbelt Provinces. At the time of the study, Northwestern Province had no functional fingerling producers, and therefore, fish farmers were dependent on distant suppliers.

The relative technical performance of different producer types (Table 1) is determined by management practices and by system type (ponds or cages). Water availability does not seem to be a limiting factor, as the bulk of fish production is performed in the vicinity of water bodies. Economies of scale definitely play a role in overall productivity, as it allows for buffers (feed, seed, storage) and financial flexibility (WorldFish, 2014). To put into context the performance of Zambian smallholder systems, it could be noticed that the yields of similar Cameroonian tilapia pond systems not consuming commercial feeds range from 3.4 and 7.5 t/ha (Efole Ewoukem et al., 2012). The performance of Zambian large-scale systems could be compared with that of similar intensive Indonesian tilapia systems, consuming commercial feed, featuring cage-based FCR of 1.7 and pond-based FCR of 1.65 (Pelletier and Tyedmers, 2010).

Table 1
Production performance indicators per Zambian aquaculture system type (2015-2016)

Production system type	Number of instances	Mean annual output (t/y)	Yields (t/ha)	FCR (kg/kg)	Contribution to fish supply
Smallholders' semi-subsistence ponds	~11 000	0.04–0.4	1.9	5.0	6.4%
Smallholders' commercial ponds	853	1–5	5.2	2.0	6.8%
Medium-scale ponds	7	20–200	7.6	2.0	3.2%
Large-scale ponds	13	200–1500	16.0	2.0	7.5%
Large-scale cages	12	1500–4 000	880.0	1.6	67.4%
Extensive ponds/ stocked water bodies	N/A	N/A	<0.9	>5.0	8.6%

Feed Conversion Ratios (FCR) were computed from primary data and validated against literature and expert opinions.

The other links in the value chain cater to, a large extent, the producers (Fig. 3): some are input providers and the others form distribution structures.

Seed (broodstock, fingerlings) is produced by the large fish producers, by commercial hatcheries, and by government-run hatcheries. The two first types cater to the most affluent fish producers, while the government-run hatcheries cater to smallholders. The latter are part of the government's provincial and national research stations. Government-run hatcheries are often underfunded to the extent that they are currently unable to fulfil the growing demand for fingerlings by smallholders and sell predominantly mixed-sex fingerlings. Selling price is commonly around 0.045 EUR per fingerling. Roughly one of such facilities exists per province, yet not all are functioning at full capacity. Commercial hatcheries use either homebred broodstock (size-selected over several generations) or imported strains such as the GIFT, and use commercial feed. They sell mainly sex-reversed fingerlings, at 0.03–0.23 EUR per fingerling.

Commercial feed producers are established animal (poultry, swine, and cattle) feed producers, which in recent years have invested in the aquafeed market. Fish producers complained about the quality of Zambian commercial aquafeed (protein content, floatability, shelf life). In recent years, two of the largest cage producers have partnered up with international feed producers to set up aquafeed mills in the Lake Kariba region (Siavonga District). These two aquafeed plants are running as of 2018.

Fish processing (e.g. smoking, filleting) is very marginal in the country. Most fish is sold either fresh whole on ice or blast frozen (see also Krishnan and Peterburs, 2017).

Fish trade is complex, as it encompasses wholesalers, different types of retailers, and importers (Fig. 3). Farmed fish is overwhelmingly consumed by urban consumers. One major company has taken on the role of wholesaler in the farmed fish supply chain, purchasing a significant amount of fish from medium- to larger-scale farms in Zambia and is also a major importer. Some of the larger-scale fish producers have wholesaling activities integrated into their operations and have set up depots in the larger towns. Retail is performed by a variety of actors, including the so-called “City Ladies” (who operate in wet markets and conduct mobile vending), dedicated fish stores, butcheries, supermarkets, other grocery stores, hotels and restaurants. In addition, there are many institutional buyers (e.g. schools, public servants, clinics). Both medium-scale and smallholder producers also engage in farm gate sales. Trade within rural areas consists of producers selling at their farm gates and a smaller portion, who reside closer to district capitals, transporting their fish for sale in urban centres.

Product differentiation for farmed fish being sold is limited and mainly based on size (small 100–200 g, medium 200–400 g, large >400 g) and product (fresh or whole frozen). In Zambia, consumers favour consuming one entire fish each per meal, rather than sharing a larger one (see also Malumbe and Musuka, 2014). This results in medium- to high-income consumers, who can afford to purchase bigger fish, favouring larger sizes in particular (Genschick et al., 2018). Smaller sizes are more popular in low-income consumer markets. Imported tilapia is sold frozen and has a lower price per kg (Kaminski et al., 2018), as a large proportion of it (be it legal or irregular imports, estimated by certain stakeholders to be 50:50) consists of ‘by-products’ of tilapia produced in Asia for other markets (see also Kaminski et al. (2018)).

3.2. Assessment of the Zambian aquaculture value chain's sustainability and inclusiveness

3.2.1. Economic

Table 2 presents the operating accounts for the five types of farmers, small retailers and wholesalers. This shows that all categories of actors

Fig. 2. Number of smallholder fish farmers in Zambia and area occupied, per province (2014). Source: Department of Fisheries (2015).

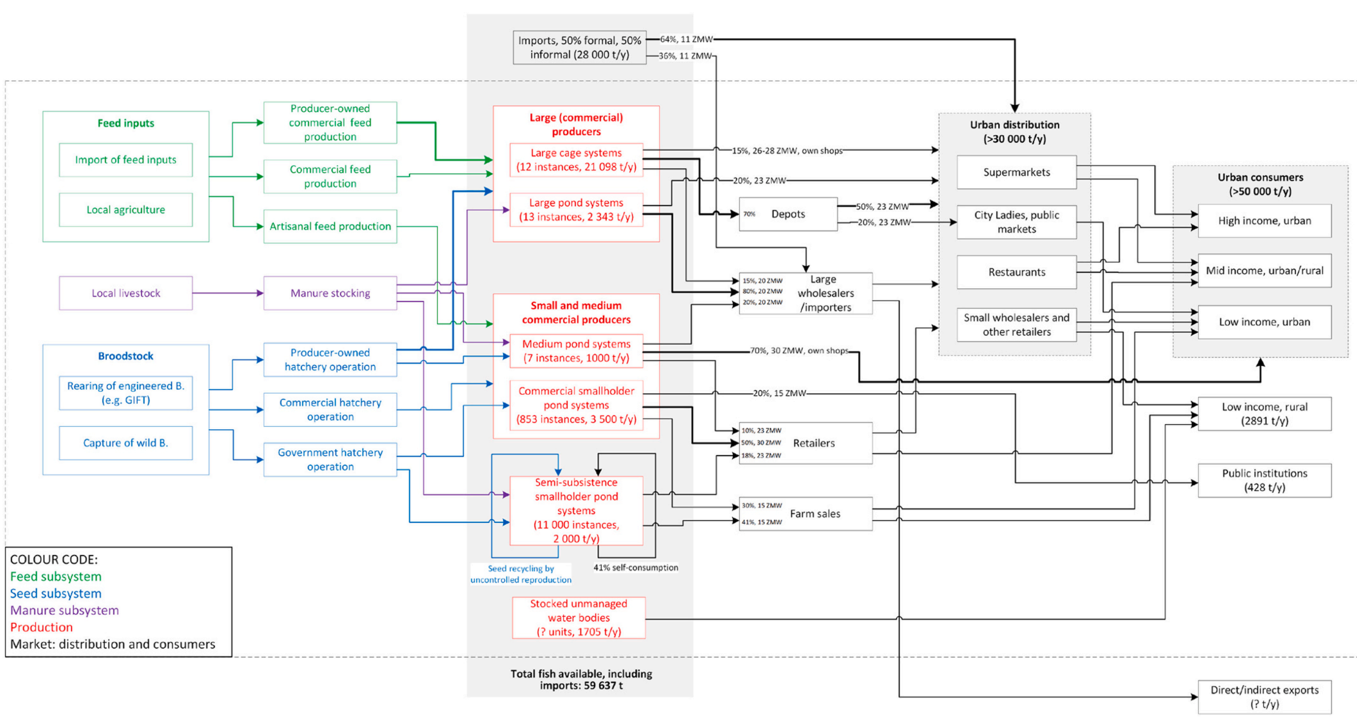

Fig. 3. Main flows among key actors within the Zambian aquaculture value chain in, 2015–2016, including price structure (prices expressed in Zambian Kwacha ZMW per kg). Thicker lines represent the most important volumes.

are economically sustainable, in the sense that they generate a profit and have a positive return on investments. However, there are major differences in the levels of profitability. A couple of methodological choices should be considered when interpreting these results. First, production includes the value of fish used for home consumption, at local market prices. Given the importance of fish for household nutrition for smallholder semi-subsistence farmers, and that it is a cost foregone to purchase fish for consumption, the value of fish consumed at home could

Table 2
Financial analysis of actor types (annual costs and profits) in 1000 Zambian Kwacha.

	Producers					Distribution	
	Small-scale semi-subsistence pond	Small-scale commercial	Medium-scale pond	Large-scale pond	Large-scale cage	Small retailers (City Ladies)	Wholesalers
Volumes (t)	0.2	5.0	100.0	1300.0	2 000.0	10.4	6 060
Sales							
Fresh	1.7	112.5	2 730.0	27 040.0	45 100.0	270.0	9 000.0
Frozen whole local	–	–	–	–	–	55.7	118 560.0
Frozen whole imported	–	–	–	–	–	–	15 120.0
Fillets	–	–	–	–	–	–	16 800.0
Smoked	–	–	–	–	–	–	20 400.0
Self-consumption	1.1	–	–	–	–	–	–
OUTPUT	**2.8**	**112.5**	**2 730.0**	**27 040.0**	**45 100.0**	**325.7**	**179 880.0**
Intermediate goods and services	2.3	36.3	825.6	3 853.9	8 625.8	260.4	120 897.4
Wages	–	24.3	272.7	8 100.0	7 200.0	–	3 456.0
Financial charges	–	2.5	50.0	6 000.0	6 500.0	–	25 000.0
Taxes	–	3.4	85.9	1304.5	3 077.6	–	10 878.7
Depreciation	64.0	4.4	615.7	5 376.7*	14 166.7	30.0	3 493.0
COSTS	**2.4**	**70.9**	**1849.9**	**24 635.1**	**39 570.1**	**260.4**	**163 725.2**
Net operating profit	0.4	41.6	880.1	2 404.9	5 529.9	65.3	16 154.8
Net value added**	0.4	71.8	1288.7	17 809.4	22 307.6	65.3	55 489.6
Net value added/t	2.0	14.4	12.9	13.7	11.2	6.3	9.2
Profit margin (%)	14.0%	37.0%	32.2%	8.9%	12.3%	20.1%	9.0%

Source: Authors' calculations based on primary and secondary data. Notes: *We were unable to obtain data on establishment costs for the large-scale ponds. We have estimated a value based on the medium-scale ponds. **Depreciation excluded. All amounts are expressed in 1000 Zambian Kwacha (ZMW), except when indicated otherwise.

not be excluded from the analysis. Nevertheless, the choice to include fish consumed at home using market prices assumes that all fish could be sold in the local market, which in the case of remote farmers is questionable. Second, for farm labour only actual costs are included, i.e., without considering household labour as a cost. This choice was made, as we consider each value chain actor as an entrepreneur for whom the business profits are their income.

Highest profit margins are found for small- and medium-scale commercial pond farmers (37% and 32%, respectively). In contrast, semi-subsistence smallholder farmers have a profit margin of only 14%. With the generally broad livelihood portfolio of semi-subsistence smallholder farmers, the average annual earnings (including forgone costs) of 390 ZMW or 32.5 EUR[4] can be interpreted as supplementary household income. In comparison, the average annual minimum wage in Zambia is 714 EUR and the annual living wage was estimated at 3 403 EUR at the time of the study (https://wageindicator.org/salary/wages-in-context). Moreover, these very low annual earnings do not adequately compensate the household labour invested in the activity as they are the equivalent of 12 working hours by year at the average annual minimum wage and families spend more time farming fish in their pond. As the average annual earnings of semi-subsistence smallholder farmers are far below the average minimum wage, we can assume that if aquaculture was the main activity of these farmers, they would be operating at an unsustainable level. The annual net operating profit generated by smallholder commercial farmers (41,600 ZMW or 3467 EUR) is higher than both the average annual minimum wage and the annual living wage. Small retailers also have a relatively high profit margin but small operating profits. The composition of the costs for inputs (included in intermediate goods and services) differs substantially by farm type, for example the share of costs allocated to (home-made and commercial) feed, wages, and capital depreciation (more details are available in the Supplementary Material).

At the whole chain level, we analysed direct value added. A comparison of the share of value added, net operating surplus, and wages contributed to the total by each actor type (Fig. 4) shows that from a macroeconomic perspective, the contribution of small actors as small

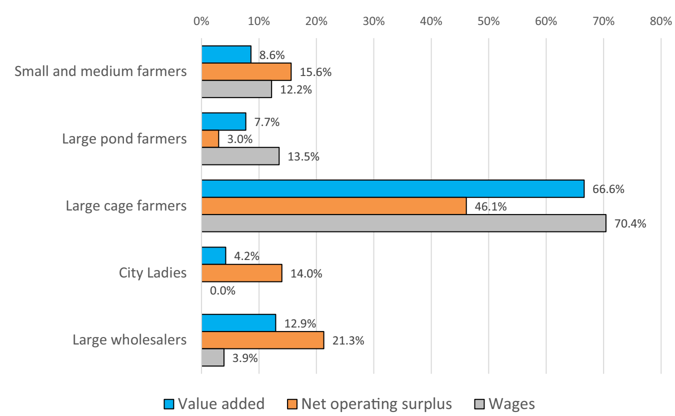

Fig. 4. Share of direct value added, net operating surplus, and wages by value chain actor (2015-2016).

(and medium) farmers and City Ladies to growth is low, but a large part of value added they create is operating profit for themselves. This means that there is potential to increase the incomes of these vulnerable categories with higher performances and potential for a higher contribution to growth if the individual businesses improve. In contrast, large-scale cage producers contribute the majority of direct value added (67%) and create many salaried jobs (70% of wages). Currently, economic growth and jobs depend on the large players, and it is important that the larger-scale commercial sector can continue to grow and generate economic benefits for the country.

The economic analysis only shows the situation at the time of this research, which hides the significant shifts that have taken place over the past decade. Up until about 2008, smallholder farmers dominated the sector, which was very small in size overall. A few large-scale firms entered the market thereafter and it quickly quadrupled in size. Smallholders continued to produce more or less the same volumes, but currently their volumes make up only about 25% of the total, whereas their contribution was almost 80% before 2008 (Kaminski et al., 2018). The value chain can be considered moderately economically inclusive from the perspective of smallholders and medium-scale farmers.

[4] A ZMW to EUR conversion rate of 12:1 was used.

However, the activities of the roughly 11 000 semi-subsistence smallholder farmers are not economically viable and sustainable. These results are not aligned with those recently presented in Namonje-Kapembwa and Samboko (2020), but their data are representative of only a handful of producing areas, and their analysis focuses on what we define as commercial smallholders.

3.2.2. Social

The social analysis focused on several sub-components of the six domains mentioned in the Methodology section. Summarised results from each domain are presented below.

Working conditions: Labour laws in Zambia are in line with the eight fundamental ILO international labour conventions and the International Covenant on Economic, Social and Cultural Rights (ICESCR) and International Covenant on Civil and Political Rights (ICCPR). From discussions with larger-scale producers, it appears they respect these standards and consider their hiring and employment conditions as “fair” or “very fair”. This study did not triangulate whether employees who were hired to work for these producers also believe their working conditions are equitable. Casual labourers, many from rural areas, comprise workers at larger-scale farms given the need for seasonal labour (e.g., harvesting). Such employment practices do not appear contrary to labour laws, although casualization[5] is illegal in Zambia.[6] Job safety practices at larger farms and feed mills and wholesale centres were evident during data collection visits.[7] No larger-scale farms employ children, but children do assist their parents carrying out many fish farming duties in rural areas.

Land and water rights: The Lands Act of 1995 (Government of the Republic of Zambia, 1995) recognises two land tenure systems in Zambia, namely state and customary. An important aspect of the Act is its provision for the conversion of customary tenure into leasehold tenure. The provision has enabled large tracks of customary lands to be converted to state lands for agricultural and non-agricultural development purposes, which in some cases, displaces rural people either voluntarily or involuntarily (Hall et al., 2017). Zambia has a Land Resettlement Programme that was only recently guided by a National Resettlement Policy.[8] The Voluntary Guidelines of the Governance of Tenure (VGGT) (FAO, 2012) are not well known or used by large-scale investors who displace people when they acquire land (Chinyemba, 2019; Chu et al., 2015). It appears larger fish farms in Zambia adhere to the VGGT. All larger-scale farms included in this study indicated they acquired their land through appropriate channels,[9] either by purchasing the land and obtaining a title deed or by following customary norms and practices. Smallholder farmers culture fish on customary lands and primarily access water from perennial streams or by tapping groundwater by digging their ponds in wetland areas.

Gender equality (and youth inclusion): Women comprise 8% of the workforce in the value chain (Krishnan and Peterburs, 2017). All larger-scale producers indicated their work forces are male-dominated as they believe farming fish requires a greater amount of physical strength that they claimed men possess. Youth are also employed by larger-scale farms, along with women who process fish or cook meals for farm labourers. Women residing in urban areas are very active in the trading of farmed fish. Men comprise most fish producers in rural areas according to registers accessed from district fisheries offices. For example, 60% and 84% of fish producers are male in districts in Northwestern and Northern Provinces, respectively. Women are involved in production by feeding fish or maintaining ponds and harvesting fish. Rural women’s access to or ownership of key aquaculture assets is limited, including land. Other assets such as shovels, hoes, and wheelbarrows used for constructing or maintaining ponds are generally owned by men. No labour-saving aquaculture technologies used by women were identified during the study. Youth involvement in fish farming in rural areas remains questionable given a lack of access to land and water (WorldFish, 2014), and especially female youth. Lack of ownership of land prohibits youth from accessing loans by using land as collateral (Byamugisha and Ansu (2017).

Food and nutrition security: Farmed fish from larger-scale farms is cost-prohibitive for rural people and the urban poor (Genschick et al., 2018) and more expensive than imported fish. Prices for farmed fish obtained in urban centres for this study ranged from around 20 to 35 ZMW/kg (1.7–2.9 EUR). Farmed fish in rural areas is cheaper (as low as 10 ZMW/kg or 0.83 EUR/kg in some areas) given fewer costs associated with production and presumably poorer purchasing power by most rural people. Fish production of semi-subsistence smallholders plays an especially important role in providing enhanced food and nutrition security in rural areas and diversifying agricultural production.

Social capital: Fisheries extension services are provided intermittently to smallholder producers or never at all given a lack of financial and human resources at district level. There were no non-government organisations in Zambia at the time of the study with the capacity to complement the limited services provided by the public sector. Farm cooperatives exist in rural areas, although mostly to secure crop inputs and market maize through government-supported programs. A few cooperatives visited during the study were involved in fish farming or fingerling production. Their involvement appeared to be the result of targeted aquaculture development projects, and therefore, lacked a strong business orientation. Such development projects in Zambia often provide a combination of hand-outs and technical training, without necessarily strengthening the business and management skills of farmers, thus promoting fish farming more for food production than as a business that can sustain itself after the life of the project (see also Kaminski et al., 2018).

Living conditions: Very few aquaculture value chain activities (e.g., via direct or indirect employment) contribute to improving the living conditions of rural people other than the large- to medium-scale producers located in rural settings. Two fisheries vocational training institutes exist in the country and one university that has a fisheries degree program, although rural people do not have the financial means to afford to attend these tertiary schools to advance their technical training and practical skills in aquaculture. Smallholder production enables the consumption of fish and/or provides smallholders with some source of cash (or barter opportunities) to purchase additional food or non-foodstuffs or pay for their children’s school fees. Yet, given low productivity level of the semi-subsistence smallholder production system, aquaculture cannot contribute significantly to improving living conditions of most rural people.

The results suggest the aquaculture value chain in Zambia is not socially sustainable and nor is the economic growth it has created inclusive (see also Kaminski et al., 2018). The implementation of the National Aquaculture Development Plan (2015 to 2020) that was designed to support smallholder farmers to shift from practicing “subsistence” fish farming to farming as a business (MoAL/FAO, 2015) has not led to significant change for the vast majority of smallholders who still operate at a semi-subsistence level. Recent growth in the sector primarily benefits the larger-scale producers and other value chain actors supplying the gap for fish in the country.

[5] The act of engaging an employee on a casual basis for a job that is of a permanent nature.

[6] See https://www.ilo.org/africa/countries-covered/zambia/WCMS_449885/lang–en/index.htm

[7] For example, life jackets and floating feeding stations were being used at the two cage farms visited on Lake Kariba, mouth/nose guards and hard hats were being used in feed mills, and rubber boots and protective gloves at the fish wholesale centre.

[8] See https://landportal.org/library/resources/zambia-national-resettlement-policy

[9] This was not triangulated by speaking with local authorities or residents about the land acquired.

3.2.3. Environmental

The LCA results show that environmental impacts are correlated with the quality of management, regarding water, feeding strategy, cycle planning, record-keeping; and thus confirming a reported correlation (Dauda et al., 2019). Adequate management of aquaculture systems demands both expertise and resources. The semi-subsistence pond systems are the less managed ones and feature the highest (negative) impacts. These impacts, led by climate change, eutrophication, and land use are due to the relation between inputs (even if low) and yields. Poor management implies, for instance, lower yields due to water quality issues.

A contribution analysis (to impacts) highlights and explains differences in performance across producer types (Fig. 5). Among large-scale producers, cages have lower overall impacts than ponds (Fig. 5), despite large feed demand of the former, due to the higher FCR of the latter. Larger resource demands of pond systems (land occupation, pumping, and direct emissions due to manure use) do not seem determinant to impacts. Among pond systems, large-scale systems feature higher impacts than well-managed medium-scale and smallholder commercial ones, while smallholder semi-subsistence and extensive systems have very high impacts per produced t of fish in relation to other pond system types. The reasons are multiple, and include economies of scale, feeding efficiency and other management-derived performance aspects, as well as the extent of extensification. The extent of extensification (as represented by the stocking density and FCR) seems to play an important role in determining environmental performance, for instance, penalising large-scale pond systems and pure extensive systems (such as stocked water bodies).

The overall contribution to impacts of the value chain is dominated by human and freshwater toxicity, mainly associated with the agricultural phase of feed production, especially in large-scale cage systems. As often found in the literature, feed provision is the main driver of most environmental impacts for all system types. Extensive and under-managed systems feature higher impacts than intensive and/or well managed ones, but the overall environmental performance of the value chain is determined by the dominant production of large-scale cage systems (Table 1), which feature relatively low impacts.

Certain well-managed aquaculture systems in Zambia can be deemed environmentally sustainable as compared with other global cultured tilapia systems (e.g. Avadí et al., 2015; Efole Ewoukem et al., 2012; Pelletier and Tyedmers, 2010): systems across countries with similar positions in the extensive-intensive production continuum feature environmental impacts within the same orders of magnitude.

3.2.4. Sustainability of aquaculture production systems in Zambia

A comparative sustainability assessment of the different production systems (Table 3), as previously proposed in the literature (e.g. Avadí et al., 2014), allowed for the identification of certain particularities. For instance, ponds poorly managed by semi-subsistence smallholders are clearly environmentally unsustainable, while economically they generate small profits and are not equipped to sustain production or enhance productivity, and thus, can be considered as a secondary or tertiary means of making a living. On the contrary, Table 3 shows that the situation of commercial pond smallholders is the better trade-off between the different dimensions of sustainability: they perform socially and economically and are economically viable in comparison with other systems.

In the long-term, sustainability for semi-subsistence smallholder farmers will depend on labour productivity and access to markets (Kruijssen et al., 2018a). The profits earned by semi-subsistence smallholder farmers are low and their relative contribution towards national production is decreasing. For all producers, long-term economic sustainability will depend on the competition with imports and consumers' recognition for quality. A recent analysis of the Zambian fish sector (Tran et al., 2019, p.343) suggests that "further investment in aquaculture could provide a solution [to the fish deficit in Zambia and the dominance of imported fish] if input markets for seed and feed are appropriately developed".

The economic growth throughout the value chain is not very inclusive. Generally, smallholders' lack of access to microfinance, key inputs, extension services and vocational and technical training, and to more vibrant output markets has inhibited them from moving from a semi-subsistence production system to one that enhances their productivity and sustainably increases their incomes.

The value chain faces several social issues. Employee bases at larger fish farms are dominated by men. Whilst youth (males) are employed as general workers on larger farms, it appears their participation in rural fish farming is limited as is that of rural female farmers. Farmed tilapia produced for urban markets is cost-prohibitive for poor consumers. Extension support and training opportunities for smallholder farmers are few. Nevertheless, the current production systems employed by the majority of rural smallholder farmers enable them to access fish for food (with nutrition security implications) and to generate small amounts of income.

The overall aquaculture supply chain has the potential to contribute far more to sustainable development in Zambia, yet various challenges remain to be overcome. Efforts to address these sustainability challenges should target smallholder producers, as they are a large population

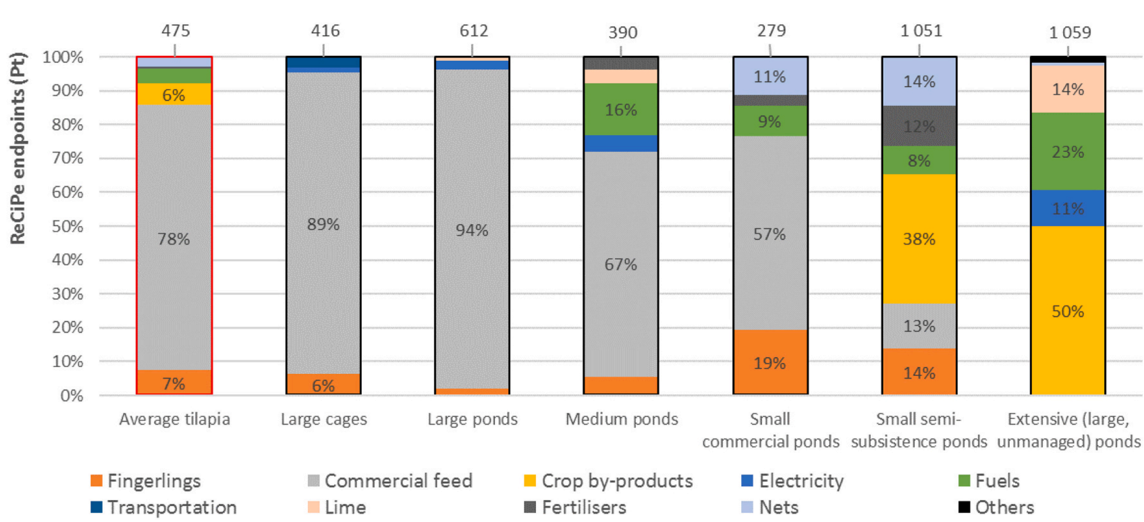

Fig. 5. Contribution analysis per system type for the production of 1 t of tilapia in Zambia (2015-2016), impacts are expressed as dimensionless single scores (ReCiPe endpoints).

Table 3
Sustainability comparison of Zambian aquaculture system types.

Producer type	Resilience[a]	Economic performance	Social performance	Environmental performance[b]
Pond smallholders (semi-subsistence)	★ Low: very sensitive to the quality and availability of inputs, including water	★ Very low profitability, little value added, few salaried jobs	★ Low input, low output system, yet important contribution to food and nutrition security and some income generation. Lack of women and youth involved.	★ Very low per t Very high per ha
Pond smallholders (commercial)	★★ Medium: flexible to varying quality and availability of inputs, thanks to management	★★ Good profitability, moderate value added, few salaried jobs	★★★ More intensive system, with apparent greater economic returns on investment that in principle improve social conditions of farmers	★★★ Very high per t Low per ha
Medium-scale pond farmers	★★ Medium: flexible to varying quality and availability of inputs, thanks to management	★★ Medium profitability, moderate value added, few salaried jobs	★★ Contribution to local employment, potential to supply smallholders with better quality seed. Source of fish for larger markets/better-off households.	★★ High per t Low per ha
Large-scale pond farmers	★★★ High: very flexible to varying quality and availability of inputs. If integrated with livestock, close to self-sufficiency	★★ Medium profitability, high value added, medium salaried jobs	★★ Contribution to local employment, potential to supply smallholders with better quality seed. Source of fish for larger markets/better-off households.	★★ High per t Very low per ha
Large-scale cage farmers	★★ Medium: somehow sensitive to the quality of inputs (feed)	★★ Low profitability, very high value added, contribution to growth (fish, feed, seed), many salaried jobs, not viable in the international economy	★★ Contribution to local employment, potential to supply smallholders with better quality seed. Source of fish for larger markets/better-off households.	★★ High per tonne
Extensive ponds/ stocked water bodies	★★★ High: self-sufficient system, but very low output	★ Not studied but likely similar to smallholder semi-subsistence farmers	★★ Lack of available data, but likely provides a source of fish to rural smallholder for food and nutrition security and income	★ Very low per t Very high per ha

The lowest score per category is represented by one star, while the highest has three.
[a] "Resilience" refers to the perceived capacity of systems to recover from environmental, economic or social perturbations (Prosperi et al., 2016).
[b] "Performance" is here understood as the inverse of environmental impacts intensity.

whose activities and performance represent —or may represent— a large and important contribution to rural development, food security, and even to resilience and adaptation to climate change (see for instance FAO (2014b)).

3.2.5. Specific diagnosis of the smallholder producer: Are they contributing to the value chain growth?

Due to their management practices, the production costs of semi-subsistence smallholders are relatively low much like their yields. Net revenues are so low, however, that even if the farmers sell all their production, they would be far below the minimum wage. The average 100–200 m^2 pond produces around 10–30 kg per year, mostly using an extensive system and likely practicing partial harvesting (Genschick et al., 2017b). Lack of proper management (e.g. water management, feeding strategy, cycle planning, record-keeping) is one of the key factors hindering any improvements. Lack of extension support and business and technical training coupled with their lack of access to finance and quality inputs prevent semi-subsistence smallholder farmers from adopting better management practices.

Commercial smallholders who adopt a semi-intensive production system are more performant but still face difficulties and their performance could be improved. They have higher costs of production as they use commercial feeds and invest in other inputs and areas of production. As a result, they achieve higher levels of production, net income and higher profit margins. They do face some similar constraints as their semi-subsistence counterparts do, including low access to high-quality seed, which in some cases, requires them to import seed over long distances. They have limited or no access to technical services except from government extension officers, who in turn have limited resources and skills to provide these services. While the recent surge in interest in (commercial smallholder) fish farming is encouraging, without newly-honed skills and access to good quality seed coupled with high levels of investment establishing their ponds and using commercial feeds, long-term growth of the sector could be threatened.

4. Discussion

Results are discussed in the perspective of improving the sustainability of smallholder producers and increasing the inclusiveness of the aquaculture value chain in Zambia.

4.1. Implications for a way forward to enhancing the sustainability of smallholder producers

Past attempts to develop smallholder aquaculture in Zambia can be characterised as being poorly grounded in the realities faced by producers. Development initiatives have tended to promote fish farming as a means to increase food and nutrition security without understanding first what motivates smallholder farmers to get involved (Harrison, 1996). Their longer-term, sustained participation in the sector would seemingly entail that their fish farming systems are productive and relatively profitable to justify their investments, similar to those they make when pursuing other livelihood activities. For smallholders to achieve better production outcomes from fish farming, they need improved access to inputs and other resources, training to increase their management skills, and links to output markets that demand their products. Interventionist approaches that target smallholder farmers for increasing rural food production only rather than equip smallholders to farm fish more as a business, risks repeating outcomes that have stunted the growth of the smallholder aquaculture sector to date (Kaminski et al., 2018).

The major constraints for most smallholder fish producers to better manage their activities and increase technical and economic performances include low availability of quality fingerlings, lack of access to good quality yet affordable feed, lack of access to financing mechanisms and suitable business models, inadequate extension services, and a severe lack of technical knowledge and business management skills. By improving their performances and management, they will have potentially less impact per tonne of fish produced, and the value chain will globally be more environmental friendly (see section 3.2.3). Moreover, they will generate more income than the living or even minimum wage in the country and contribute more efficiently to economic growth (see section 3.2.1). In this section we propose several strategies and models that aim to alleviate the abovementioned constraints and enable greater economic, social, and environmental sustainability of the smallholder producers in Zambia. We focus our discussion on four themes to enable different stakeholders to support smallholders to "graduate" from relatively unsustainable conditions to a more sustainable one that harnesses combined efforts by the private and public sectors and research and development organisations.

4.1.1. Strengthening aquaculture development policies and strategies

Policy action should be tailored according to the type of aquaculture system and actors. This entails recognising that most smallholders in Zambia often consider fish farming as a secondary or tertiary activity given the constraints they face (Kaminski et al., 2018; Kruijssen et al., 2018a), and instead, focus much of their investment efforts producing crops and livestock (see section 3.1 and the Supplementary Material). There is need to explore a more balanced development model of the aquaculture sector, based on favouring smallholders to help satisfy the diversity of markets and consumers of farmed fish. This should include developments and investments in private hatcheries and nurseries (Siriwardena, 2007), producing fingerlings from genetically improved strains endemic to the northern region (Genschick et al., 2017b), while promoting recognition of the value of using larger and mono-sex fingerlings in the medium to longer term.

Increasing the supply of microfinance to farmers is part and parcel to increasing their access to improved fingerlings and feeds (Ataguba and Olowosegun, 2013). There is need to develop finance products that take into account differences in fish farming compared to crop and small livestock (e.g., poultry) production, most notably the relatively long growing cycles and continued need to purchase feeds throughout the production cycle (APF, 2014; Genschick et al., 2017a). In addition, there must be efforts to strengthen technical knowledge on aquaculture and business skills, as without the two, farmers are highly likely to fail to pay back their microfinance loans and become indebted.

Strategies for increasing fish availability in the country are equally needed, by supporting the types of systems producing lower environmental impacts, namely well managed pond systems in water-abundant regions and larger-scale cage systems in water bodies yet to be exploited. For aquaculture to expand, the main target needs to be on locations where access to water is prevalent, as the additional costs for pumping water are a major constraint for economic sustainability and profits. This recommendation is in line with the National Aquaculture Development Plan of Zambia (MoAL/FAO, 2015), which has identified the high-potential aquaculture zones in the north as the areas for aquaculture development. In water-scarce areas of Zambia, such as mapped by Matchaya et al. (2019), year-round pond aquaculture should not be promoted, or after detail study of those areas, appropriate technologies or systems should be designed to fit the circumstances.

Curbing fish imports, by border enforcement to reduce irregular imports and custom barriers to discourage imports of lower quality fish, would even the competitive field and benefit the entirety of the value chain. The immediate potential reduction in fish availability for poor consumers should be concurrently (and thoroughly) considered when implementing such policies. Related, research on what sizes and traits of domestically produced farmed fish are preferred by poorer male and female consumers to inform breeding programs and different producers types could ensure the supply of farmed fish in the country is pro-poor and gender-responsive (Murphy et al., 2020).

4.1.2. Innovations

There is need to design and test appropriate aquaculture labour-saving technologies with women, men, and youth, with a strong focus on testing and promoting integrated aquaculture agriculture systems and water management practices to enhance productivity of smallholders. Clear gains can still be made among the smallholder and medium-scale farms. A focus on efficiency will not only be beneficial to economic performance, but will also have a positive impact on environmental performance. Maulu et al. (2019) reviewed the latest science and technology developments in the Zambian aquaculture sector and found that the sector is lagging behind in many regards including fish genetic breeding and improvements, fish health and disease management, sustainable feeds and nutrition, production systems, and water environmental management. Comprehensive studies of the smallholder aquaculture sector are needed to determine the suite of innovations that are needed at this point in time. A demand-driven approach would increase the likelihood that technologies developed by stakeholders in the sector are fit for purpose and address the needs of smallholder farmers and other value chain actors and circumvent the social and gender issues that constrain especially women from meaningfully participating in and benefiting from aquaculture (Kruijssen et al., 2018b).

4.1.3. Gender and youth

Greater efforts are needed to bring women and youth more holistically into aquaculture production in rural areas (Kruijssen et al., 2018b) and design and implement policies that would ensure a larger percentage of women are employed in multiple capacities throughout the sector (see section 3.2.2). Krishnan and Peterburs (2017) found that women make up a small fraction (<10%) of the workforce in the aquaculture value chain, and in line with our study, highlight that the perception that aquaculture jobs require a great deal of physical strength deters women from seeking employment in the sector. Youth are equally missing in the value chain, accept as labourers on larger farms and in feed mills (see also Krishnan and Peterburs (2017)). Broadly speaking, government policies and civil service organisations can begin to address these social exclusivity issues using a number of strategies including working with business firms via awareness raising programs and helping them to design better workforce conditions that reduce the misconceptions that employment in the aquaculture sector requires physical strength or is a "male" profession. Transforming the sector to ensure it is more equitable and inclusive in its hiring practices requires a fundamental shift in beliefs and attitudes by senior management in firms and current employees to create enabling environments for those misrepresented in their workforce.

Programs aiming to integrate more women into rural aquaculture activities must keep in mind women's significant role carrying out unpaid (domestic) tasks to avoid inadvertently burdening them with extra work while promoting aquaculture more generally. Improving women's and youth's access to land and water resources in rural areas for fish farming and other related activities is imperative, yet requires deeper engagement with traditional leaders who govern customary lands in rural areas and with Government who can stimulate dialogues with these leaders to ensure access to land and water resources are more equal.

Rural food insecurity and child malnutrition remain major stumbling blocks to development in Zambia, with lack of diversity in food production and availability being highlighted as main contributing factors (Mwanamwenge and Harris, 2017). More widespread fish production in rural areas could improve especially the diets of women and children in the first 1000 days (Longley et al., 2014), while recognising that the impact pathway from food production to enhanced health and nutrition is complex and requires a strong focus on women's empowerment to ensure benefits to fish production reach women and children consumers (see Herforth and Harris (2014)).

There is also need to understand the aspirations of rural and urban women and youth to get involved in the aquaculture value chain to ensure various entry points for these groups are relevant and enable their sustained participation. Expanding the use of information and communication technologies (ICTs) throughout the aquaculture value chain could be one option for attracting youth into the sector by providing paid services. ICTs could be used to enhance pond site selection, monitoring fish growth, health, and water quality, understanding market price differences and linking to wholesalers and retailers, to name a few.

4.1.4. Capacity development

Greater investments are needed in aquaculture training at all levels to ensure the current technical and vocational institutes have enough qualified lecturers, for students to receive enough practical experience, and rural farmers have access to such training as opposed to only that provided occasionally (if at all) by fisheries extension officers (Kirui and Kozicka, 2018). More effective extension services provided by the agricultural sector (including the private sector) may be emulated for aquaculture, once or if the required critical mass is achieved. This would improve access by smallholders to both technical know-how and inputs and possibly output markets. Improved know-how would enable better management and thus simultaneously increase socio-economic performance and lower environmental impacts.

4.2. Implications for inclusive and sustainable value chain development

Piloting and scaling inclusive business models (Kaminski et al., 2020) could improve linkages between smallholders and other private actors, thereby increasing smallholders' access to technologies (Chaweza and Nagoli, 2018), key inputs, microfinance, training and output markets. Examples of such models could include contract farming, certification, farmer-owned businesses (associations or cooperatives), or setting up private-public partnerships (e.g., via Aquaparks (AfDB, 2016; MAAIF, 2017)). Development efforts to support smallholder fish farmers often focus on increasing their access to inputs or improving their management practices, yet fail to create meaningful linkages between smallholders and viable output markets. Poor linkages to output markets are due to a number of factors (Onoja et al., 2012), which require detailed study in a given context to enable smallholders to commercialise and sustain their production systems.

More integration between the different sub-chains would be not only possible, but also beneficial for the overall sector. Smallholders constitute a market for feed, seed and extension support, which could be provided by large fish farming companies, who have the capacity. Inclusiveness in a way is based on integration, coordination, and partnership. Large producers would benefit from, at a marginal cost, collaborating with smallholders, a better-trained workforce, and even a generalised improvement in purchasing power in the communities under their area of influence.

The different types of fish producers are not in direct competition (e.g. as they feature different fish qualities and different target markets and consumers). They face unique constraints but also have certain challenges in common, such as the threat that imports represent for their sales. Improved coordination and leadership among smallholders would highlight such circumstances, and engage in more successful lobbying with the government. Supporting small- and larger-scale farmers is positive for the government, as their development would contribute to different objectives such as growth, jobs, territorial development (as the activities do not develop in the same regions), balance of trade, among others.

A national platform including the private and public sectors, coupled with reinforcement of the capacity of smallholders to fully participate, would contribute to building the conditions for a strong aquaculture sector in the country. It would likely benefit different types of stakeholders, as far as their activities are only complementary in supplying fish in Zambia, and are not really direct competitors.

Increased inclusiveness in the aquaculture value chain in Zambia would imply more competition in trade activities, partially diluting the weight of large wholesalers who currently hold a larger part of the market. More competition between wholesalers and other distributors would be at the advantage of the farmers because the prices could be better negotiated.

5. Conclusions

As far as we know, this is the first study to analyse simultaneously, holistically and cross-disciplinarily, the three classical dimensions of sustainability of the Zambian aquaculture value chain.

The goal of improving the performance of semi-subsistence smallholder producers is commonly expressed in Zambia as "graduating the semi-subsistence smallholders into commercial businesses" (Permanent Secretary of the Ministry of Fisheries and Livestock, 2017, pers. comm.). Despite contribution of aquaculture as a secondary or tertiary activity, semi-subsistence smallholder operations in rural areas are clearly not sustainable. Scores of improvement-oriented measures have been proposed (e.g. Kaminski et al., 2018; Kruijssen et al., 2018a; Mushili and Musuka, 2015), yet more transversal strategies are required. These strategies would encompass policy, financing, training, infrastructure and science elements, to address the constraints faced by smallholder producers. Whether such measures contribute to improving the benefits of aquaculture as a tertiary activity, or enable its adoption as a primary one, both outcomes would be a clear progress in the context of sustainable development for Zambia. The lessons learned while analysing the Zambian aquaculture value chain are twofold. First there is a potential of upgrading for smallholder farmers from subsistence strategies to commercial ones, with external support in different domains but not in a spirit of assistance as in the past but with one of developing business skills and increase the access of farmers to the many resources they are lacking. The second lesson is that often the defence and the support to smallholders is seen as a choice between two main models: family farming against agribusiness that is taking advantage of the situation (markets, subsidies, support, interest of policymakers, etc.). In the case of Zambian aquaculture, clearly there is a way of building on mutual interest across models to enhance the sustainability of smallholder aquaculture production in the country. As the sector as a whole continues to grow, driven by the larger-scale commercial sector, it is necessary to enable smallholders, especially semi-subsistence ones, to participate in this growth.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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