Article

Economic Analysis and Improvement Opportunities of African Catfish (*Clarias gariepinus*) Aquaculture in Northern Germany

Johannes Pasch * and Harry W. Palm

Department of Aquaculture and Sea-Ranching, Faculty of Agricultural and Environmental Science, University of Rostock, D-18059 Rostock, Germany; harry.palm@uni-rostock.de

* Correspondence: johannes.pasch@uni-rostock.de; Tel.: +49-178-6570697

Abstract: A farmland based African Catfish recirculation aquaculture system with a production volume (PV) of 300 m³ was modelled under realistic market conditions in order to analyse the impact of price fluctuations on profitability. As a monoculture recirculating aquaculture system (RAS) for whole fish and the wholesaler's market, the model northern German catfish aquaculture is currently gainless, but the production is sufficient to cover all costs. The most decisive economic parameter is the low selling price (2.20 EUR/kg whole fish), which affects the returns by ±70,463 EUR/year for every ten percent (0.22 EUR) price change. Among the variable costs, feed has by far the largest impact with a share of 61.4% (42.1% of total costs). Based on the initial model every ten percent price variation of this variable input factor changes the returns by ±29,691 EUR/year, followed by energy (±5913 EUR/year), fingerlings (±4804 EUR/year), wages (±3972 EUR/year) and water (±2464 EUR/year). Larger system sizes (600 m³ PV) significantly save costs due to economies of scale and achieve returns of 175,240 EUR/year and an ROI of 11.45%. Increasing max. stocking density from 450 kg/m³ to 550 kg/m³ improves returns and ROI (40,379 EUR/year; 4.40%), but also involves higher production risks. An own fingerling production with a production of 300% above the own requirements improves returns and ROI (39,871 EUR/year; 3.57%) and leads, above all, to independence from foreign suppliers. Aquaponic integrations can generate profits, but are associated with high investment costs and the challenges of entering a new business sector. Product diversification into fillet (50% of the production) and smoked fillet (30%) generates lucrative returns and ROI (212,198 EUR/year; 20.10%). Profitability is further increased by direct marketing in the form of a farm store and the establishment of a regional "producer organisation". Our results demonstrate that under current market conditions northern German catfish aquaculture covers all costs, mainly increasing profitability through altered sales prices and feed costs. Retaining a larger part of the fishery value chain within the farm through additional benefits, further processing and product diversification improves profitability, making African catfish RAS a sustainable and economically profitable aquaculture business in Germany.

Keywords: aquaculture; aquaponics; economies of scale; RAS; profitability; ROI; value chain

Citation: Pasch, J.; Palm, H.W. Economic Analysis and Improvement Opportunities of African Catfish (*Clarias gariepinus*) Aquaculture in Northern Germany. *Sustainability* **2021**, *13*, 13569. <https://doi.org/10.3390/su132413569>

Academic Editor:
Giuseppe Antonio Di Vita

Received: 8 November 2021
Accepted: 3 December 2021
Published: 8 December 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Global aquaculture production has increased significantly by 193% from 1999 (41 mil. tons/year) to 2019 (120 mil. tons/year), with the majority of the production (91.6%) coming from Asian aquaculture [1]. Europe had a small share of global aquaculture (2.7%) in 2017 with an annual growth rate of 2.27% per year since 2000 [2]. The past years European Aquaculture growth is stagnating in many countries [3], also in Germany [4]. This is despite the fact that the European Commission is seeking for new solutions increasing sustainable aquaculture production inside the member states [5]. Recirculation aquaculture systems (RAS) have been recognised as an alternative to open water and netcage aquaculture, enabling higher stocking densities, reducing water consumption and controlling nutrient and wastewater release [6,7]. With a yearly production volume of 23,000 tons

in 2018, European RAS always had stable shares between 1.5–2% of the total production volume since 2009 [8]. In combination with plant production, so called aquaponics can be considered a contemporary and ecologically sustainable agricultural production system that supports the development of a recycling economy [9]. It can be integrated into the existing value chains, either coming from the aquaculture or the plant production side.

While the intensive production of salmonids in RAS has been established in Scandinavia, Denmark [10,11] and Poland [12], more challenging species such as pikeperch (*Sander lucioperca*) are still under development [13]. Successful RAS of African catfish (*Clarias gariepinus*) in Europe has been developed in the Netherlands and also introduced to Germany and other European countries [14]. Combined with alternative energies and cheap warm water sources, e.g., from biogas plants [15], commercial production of *C. gariepinus* in warm water RAS has increased in Germany notably by 221% between 2011 (319 t/year) [9] and 2020 (1025 t/year) [16]. African catfish RAS has the advantage that *Clarias gariepinus* can be cultivated under high stocking densities [17–19], reaches survival rates above 90% [20] and can withstand adverse water conditions [21,22]. Therefore, the combination of African catfish and RAS is applicable under regular farming conditions, reducing costs of energy and water as well as reutilising the nutrient enriched solids and wastewater on the farm.

African catfish products reach quality attributes of fillets superior to other catfish species such as European catfish (*Silurus glanis*), African catfish hybrid (*Heterobranchius longifilis* x *Clarias gariepinus*) distributed under the brand name Claresse® and Pangasius (*Pangasianodon hypophthalmus*) [23]. This is nowadays recognised also on German markets, seeking new investments into African catfish RAS and further increasing production capacity. In addition, several studies demonstrated that African catfish effluents can be used in aquaponics to produce valuable plant products such as basil (*Ocimum basilicum*) [24–26], mint (*Mentha spicata*) [27] and pumpkin (*Telfairia occidentalis*) [28]. However, the development of African catfish farms in Germany were primarily promoted by the European Maritime and Fishery Fund (EMFF) [29] in the form of investment subsidies of up to 49%, but were also supported by the Renewable Energy Law (EEG), where the use of warm water from biogas production inside the RAS was compensated with an additional subsidy (Combined Heat and Power bonus—CHP) [30,31]. The different market conditions, locations and policies, but also reports about RAS unprofitability [4,32] and whitewashed figures of plant manufacturers make it difficult for the future investor to calculate profitability of new African catfish RAS. In addition, the systems currently in use in northern Germany have not been further developed under consideration of new water filtration systems, cultivation conditions, and management strategies.

There is a variety of recent publications on RAS systems with a scientific focus on water or solid treatment [33–35], nutrient flows [36–38], bacterial activities [39–41], or aquaponic adaption [42–44]. Although economic performance is the most critical issue for the long-term successful operation of RAS, research on this issue, especially for particular species is scarce. A detailed economic review of a Tilapia prototype RAS dates from 1996 and describes three tools or models for analysing a Tilapia RAS or an investment in such a system [45]. A 2012 study on management issues in RAS identified the main problem as inadequately trained employees taking responsibility for water treatment and mechanical problems [6]. In addition, a lack of research on commercial scale RAS was identified, which is a key priority to improve performance. Similar findings were again published in a 2020 study, which identified poor management, lack of technology knowledge, high investments, and incidence of disease and pathogens as the main problems for the RAS industry. [46] A study on the economic feasibility of pangasius RAS in Vietnam concluded that 99% of investments in medium or large RAS are profitable and crucial parameters are price, yield, fingerlings, feed and investment. [47]. A recent EUMOFA (European Market Observatory for Fisheries and Aquaculture Products) publication on RAS has identified financial risk as one of the main risks, primarily due to high capital expenditure and uncertainty regarding future costs [8]. Further actual studies on RAS profitability

primarily address topics such as nursery of marine fish seeds [48,49], hatchery of carp or overwintering of carp juveniles [50,51], or the production of ornamental fish [52,53]. Whereas there are many recent economic studies for the African catfish particularly from Africa and Asia [54–56], and the importance of input factors like the feed price onto profitability of regular aquaculture systems has been very well described [57–59] the driving cost factors for African catfish RAS including the key production factors have not been analysed.

We herewith calculate the actual cost structure of African catfish RAS in northern Germany based on a model farm and regular market conditions. The different variable costs are arranged in a descending order, and allow analyses of the real effects of price fluctuations and different entrepreneurial decision scenarios on key performance indicators (KPI), illustrating the potential of cost control and system improvements. Two aquaponic scenarios allow an estimation of additional costs and benefits. Profitability and the best options to improve the economic and ecologic sustainability of these highly productive aquaculture systems are discussed.

2. Materials and Methods

All data and information for this study originate from regional African catfish farms, feed producers, energy providers, seedling producers and water suppliers, greenhouse producers as well as own data from running African catfish RAS systems and experiments in the FishGlassHouse, University of Rostock. Depending on the location, supplier contract, and scaling, the values may differ to a certain degree. The possible price and value ranges are given and an average calculation basis (CB) was chosen for the initial model.

2.1. African Catfish RAS—Initial Model

An average catfish recirculating aquaculture system (RAS) in Mecklenburg-Western Pomerania with a production volume (PV) of 300 m³ (recirculation volume 390 m³) was modelled (Figure 1). The facility was divided into four closed loops (Unit 1–4), each with 14 rearing tanks of 5 m³ and two fingerling fish tanks of 2.5 m³ each. A simplified smaller sized system has been described for the FishGlassHouse [9]. Each unit consists of four settling tanks (sedimenter) and four pump sumps, each with a biofilter installed above. The fish are fed with an automatic feeder. On average, 2.5% of the tanks are empty due to fish slaughter, restocking or cleaning, resulting in a net production volume of 292.5 m³. The investment costs are significantly influenced by scaling and location and range from 4500–7500 EUR/m³ PV. As a calculation basis (CB) 6000 EUR/m³ PV was chosen, which resulted in total investment costs (TIC) of 1,800,000 EUR.

The stocking density at slaughter or the average stocking density is a crucial variable and influences the total production output of any aquaculture farm and thus almost all other variables. For instance, the main input factors feed, seedlings, labour and water increase while energy consumption remains similar with increasing stocking densities. Average stocking densities of commercial African catfish RAS in northern Germany range between 350–550 kg/m³ PV stocking density at slaughter. The max stocking density at slaughter of 450 kg/m³ PV was chosen as CB, which corresponds to an average stocking density of 180 kg/m³ PV or 300 fish/m³ PV. This yields an annual production of 320,288 kg/year.

Figure 1. Illustration of the 300 m³ African catfish RAS initial model. The system is divided into four independent loops.

2.1.1. Variable Costs

Feed is the main cost driver in intensive aquaculture. Depending on the FCR (Feed Conversion Ratio) and feed type, feed costs vary. Economies of scale also result in better contract conditions and higher kickbacks. For this research, the use of three feeds differing in size and expense from Coppens (Alltech Coppens BV, Leende, Netherlands) was assumed. It is common to feed the fingerlings 2 weeks with 2 mm feed, then 3 weeks with 3 mm and in the fattening phase approx. 17 weeks with 4.5 mm feed [60]. The different feed costs and quantities added together result in ranges of 0.90–1.16 EUR/kg feed. For this work, an average price of 1.03 EUR/kg (CB) was chosen. The FCR depends on many factors such as stocking density, feed (frequency), fish homogeneity and other husbandry conditions such as physico-chemical water parameters. Feed manufacturers report an average FCR of 0.85 for the entire growth period [61]. Dutch catfish farming is reported at 0.80, while studies on intensive production come to a different range with FCRs of 0.83–0.90 for adult catfish > 1 kg [19] or 0.94–1.07 for staggered production semi-commercial experiments [9]. The CB for this study was set at an FCR of 0.90, which corresponds to a total feed consumption of 288,259 kg/year and costs of 296,907 EUR/year.

Energy costs depend on whether the energy is produced in-house or by an affiliate company, or whether it is purchased publicly. In African Catfish aquaculture of Mecklenburg-Western Pomerania, companies are usually integrated into a group of affiliated companies and complement each other in production. It is common for large catfish farms to have an affiliate's biogas-CHP plant generate electricity and heat that is used by the fish farm. It depends on the type of desired taxation and accounting by each company, but relatively low purchase prices are standard. A gas price range of 0.02–0.04 EUR/kWh (CB 0.03 EUR/kWh) with a consumption range of 8–12 kWh/m³PV/d (CB 10 kWh/m³PV/d) would lead to a gas demand of 1095 MWh/year and costs of 32,850 EUR/year. Since the biomass for energy production is usually produced in affiliate companies, a possible CHP bonus will not be counted towards aquaculture in this work. An electric energy purchase price ranges between 0.06–0.10 EUR/kWh (CB 0.08 EUR/kWh) with an electricity consumption range of 2–4 kWh/m³PV/d (CB of 3 kWh/m³PV/d), and results in an annual consumption of 328.5 MWh/year and costs of 26,280 EUR/year. Heat and electricity thus result in total energy costs of 59,130 EUR/year.

The fingerlings (12 g) are purchased from local or Dutch fingerling producers. The price range is 0.07–0.33 EUR per fish. As CB, 0.20 EUR/fish was chosen. *C. gariepinus* grows from 12 g to a slaughter weight of 1.5 kg in 5 months. For each kg of catfish growth, an average of 0.72–0.78 fingerlings is needed, which includes mortality. As CB,

0.75 fingerlings/kg were chosen, which, with an annual production of 320,288 kg/year, leads to a total requirement of 240,216 fingerlings at a price of 48,043 EUR/year.

The working hours and thus the wages depend on the desired processing stages and the working speed. For the initial model, the production of 100% whole fish or living fish is assumed, which means employees would mostly sort fishes and clean. As the jobs do not require special qualifications, a full-time unskilled employee can be hired slightly above minimum wage with a range of 29,000–33,000 EUR/year (incl. non-wage labour costs). For this farm, a CB of 31,000 EUR/year was chosen. One worker can handle approx. 150–350 t/year depending on the degree of automation of the RAS. With a CB of 250 t/year, 1.28 employees/year are required at labour costs of 39,716 EUR/year.

The costs for fresh, industrial and wastewater depend on whether the water is drawn from one's own well or comes from suppliers and whether the wastewater is treated on own land or can be further used. The total water costs therefore range from 0.35–2.70 EUR/m³, including wastewater. Since all large catfish farms obtain their water from own wells and partly also have their own treatment and utilisation possibilities, the CB of 0.90 EUR/m³ was chosen. The stocking density is the decisive variable for water consumption. The higher the stocking density, the higher the water exchange rate must be to ensure sufficient water quality. At a slaughter density of 450 kg/m³ (average stocking density 180 kg/m³), the exchange rate must be 22.5–27.5%/day, including the consumption of veterinary facilities and slaughtering. With a CB of 25%, 27,375 m³/year are consumed at costs of 24,638 EUR/year.

Further variable costs such as veterinary drugs, external services or material and production costs were summarised as an amount of 15,000 EUR. The transport costs are included in the sales prices. The total variable costs in the initial model are 483,433 EUR/year.

2.1.2. Fixed Costs

Depreciation is listed as the main costs among the fixed costs. The total investment (1.80 mil. EUR) is divided into material and equipment (1,309,091 EUR) and construction (490,909 EUR). Material and equipment have, depending on the equipment, a straight-line depreciation period of 8–12 years. The CB was therefore simplified to 10 years, which corresponds to a depreciation of 130,909 EUR/year. Construction is more persistent and is depreciated on a straight-line basis over 20 years, which corresponds to 24,545 EUR/year and leads to a total depreciation of 155,455 EUR/year. The system needs a manager/administrator, who incurs costs of 45,000 EUR/year. Other fixed costs, such as demand rate net (electric energy), insurance, maintenance, etc., were summarised as costs of 20,745 EUR/year. Investments are financed with different proportions of equity, debt and subsidies. For the purpose of this paper, the KPI analysis of one year of operation, a simplified form of mixed financing with 51% equity and 49% subsidies was assumed, which eliminates interest. Since the North German investors are farmers, land ownership was assumed, which also eliminates rent. A possible rededication of available production halls, significantly reducing investment costs, was not considered. Total fixed costs of 221,220 EUR/year occur.

2.1.3. Revenues

The revenues are determined by the processing stage and the sales price. For the initial model it is assumed that 100% of the fish is sold as whole fish or living fish. Assuming a mixed distribution of 80–90% to wholesale and 10–20% to Retail, the producer prices for whole/living *C. gariepinus* in 2021 in northern Germany range between 1.70–2.70 EUR/kg. An average selling price (CB) of 2.20 EUR/kg can be achieved. The total production of 320,288 kg/year generates revenues of 704,633 EUR/year.

2.2. Entrepreneurial Decision Scenarios

In the following analyses, the impact of decision scenarios on the profitability of the initial model was investigated.

2.2.1. Scenario 1—Double Production Volume

Doubling the production volume from 300 m³ to 600 m³ would result in a doubling of all input quantities (feed, fingerlings, energy, water), but at the same time quantities can be economised or prices reduced through improved economies of scale [12]. This primarily concerns the investment costs, which drop to 5000 EUR/m³ PV (3 mil. EUR). The costs for feed and fingerlings are reduced by 5% each due to double purchase quantities, energy costs by 10%. The doubled production volume requires only 85% more labour. Other fixed costs increase by 75%.

2.2.2. Scenario 2—Higher Stocking Density

The increase in max. stocking density from 450 kg/m³ to 550 kg/m³ (Average stocking density 220 kg/m³, 367 fish/m³) results in the FCR decreasing to 0.93 and 0.77 fingerlings/kg growth being required. In addition, due to increased filter cleaning and water monitoring, one employee only manages 200 t/year and the water exchange rate increases to 30%/day.

2.2.3. Scenario 3—Fingerling Production

Fingerlings are produced in-house and require a separate room. As a result of its complexity, broodstock facility and maintenance was not separated in this calculation because the broodstock can also be co-cultivated in the main fish farm.

Option 1: Fingerlings are produced for the company's own use only. In-house fingerling production raises total investment costs to 7000 EUR/m³ PV (2.1 mil. EUR) for the production volume of 300 to and fingerlings due to the need for an additional protected rearing room with tanks and equipment. Larval and fingerling feed requirements increase feed costs by 3%, and energy and water costs increase by 10%. Fingerling production requires the hiring of a higher-skilled employee which increases labour costs by 75%. Other fixed costs increase by 10%. Saved variable costs are used to calculate KPIs for fingerlings.

Option 2: The farm produces 300% of its own needs (720,647 fingerlings/year) and resells 200% for 0.20 EUR/fingerling. The rearing room and special equipment from option 1 are already existing and the rearing tanks, pipes and pumps lead to a small increase in investment costs to 7300 EUR/m³ PV (2.19 mil. EUR). The initial feed costs increase by only 7.5% due to better contract conditions, while energy and water costs increase by 15%. The trained employee learns cheaper labour for the repetitive tasks and the original labour costs increase only by 90%. The other fixed costs increase by 25%.

2.2.4. Scenario 4—Aquaponic Integration

For the calculation of an aquaponic integration, two greenhouse models were calculated using KTBL (Kuratorium für Technik und Bauwesen) online applications, which include costs of debt [62,63]. The price level from 2013 was increased by a factor of 1.33 using the price index of the Federal Statistical Office for commercial buildings and thus adjusted to the level of the second quarter of 2021.

Option 1 is a small 1000 m² greenhouse for the production of one series of tomatoes on the vine per year that are distributed to food retail market (decoupled aquaponics s.s. according to Palm et al. 2018 [64]). Tomatoes were chosen because they achieve high market prices and can produce competitive yields with improved fertiliser use efficiency in decoupled aquaponics [65]. A Venlo greenhouse was chosen, with special glass, gutter culture, drip irrigation and blackout/shading/heat insulation screen on roof and side walls which costs 509,548 EUR (509.55 EUR/m²) without artificial lighting. The variable costs include seeds and seedlings, culture pots and substrates, plant protection, fertilisation and irrigation, packaging, wages and other costs and amount to 0.99 EUR/kg tomato. Due to the 28 °C warm water of the fish farm, heating, water and fertiliser costs of the greenhouse reduce the variable costs by 3.03% to 0.96 EUR/kg. For tomatoes on the vine, a yield of 53 kg/m² are to be expected, resulting in 53 t/year and variable costs of 50,880 EUR/year. Fixed costs (depreciation, interests, repairs, insurance and other costs)

amount to 65,690 EUR/year. Tomatoes produced in aquaponics can be marketed alike organic tomatoes and achieve a selling price of 2.50 EUR/kg.

Option 2 is a 10,000 m² Venlo greenhouse for basil production with special glass and screens on the roof and side walls but with ebb and flow cultivation systems and LED assimilation lighting (decoupled aquaponics s.l. according to Palm et al. 2018 [64]). Despite economies of scale, the greenhouse costs a total of 4,474,565 EUR (447.46 EUR/m²) due to high-quality lighting. The variable costs are highly dependent on the season. The variable production costs of a pot are 0.57 EUR/pot in winter due to the increased heating and electricity costs and only 0.36 EUR/pot in summer. The average variable costs are 0.429 EUR/pot and are reduced by 4.66% to 0.409 EUR/pot due to the yearly warm water supply with the aquaculture process water. Assimilation lighting enables ten five-week growth cycles, which, with 25 basil pots/m², results in an annual production of 2.5 million pots and thus variable costs of 1,021,875 EUR/year. The fixed costs amount to 748,832 EUR/year. Marketing the product as aquaponic sustainable food, the average sales price of the plants achieves 0.85 EUR/pot for mixed sales by wholesale and retail. If at least 95% of the 2.5 million pots are marketable products, 2,375,000 basil pots/year will be sold.

For aquaponic integration, transition tanks and piping from the fish farm to plant farm must be installed, which increases the investment costs of the fish farm to 6300 EUR/m³ PV (1.89 mil. EUR). In addition, management and administrative costs can be saved by overlapping administrative tasks. For this model, savings were attributed to aquaculture, and 20% lower management costs are calculated. The main benefits of aquaponic integration are the improved marketing opportunities of fish and plants, which in aquaculture leads to an increase in the fish selling price of 5% (2.31 EUR/kg).

2.2.5. Scenario 5—Higher Value-Added Level

Scenario 5 analyses the impact of a higher value-added level through higher processing stages and direct marketing. Labour costs for simple, repetitive tasks such as filleting, smoking and selling remain at a CB of 31,000 EUR/year. For the whole process of fillet production, from emptying a tank to slaughtering, filleting, packing and freezing, there is a wide range given from 15–35 kg fillet/hour/worker (CB 25 kg/hour). From higher finishing levels such as smoked fillet, 7.5–12.5 kg/hour/worker (CB 10 kg/hour) can be produced. The average fillet price ranges between 5–8 EUR/kg (CB 6.50 EUR/kg), the average smoked fillet price varies between 10–15 EUR/kg (CB 12.50 EUR/kg). The African catfish has a fillet yield of 41%. The trimmings (59%) produced at slaughter can be sold for 40–60 EUR/t (CB 50 EUR/t). Transport, packaging and smoking requirements are included in the selling prices. Three different marketing and price variants were modelled and analysed.

In option 1, 20% of the total output is sold as whole fish and 80% is filleted. Due to the integration of a slaughter room including a cooling plant, the investment costs increase by 10% to 6600 EUR/m³ PV (1.98 mil. EUR). The cooling system and the additional consumption of drinking water lead to an increase in electricity and water costs of 10%. Labour costs increase by 77,540 EUR/year due to an additional 2.5 workers/year. The yearly production amounts 64,058 kg of whole fish, 105,054 kg of fillets and 151 tons of trimmings.

In option 2, 20% of the production is sold as whole fish, 50% is filleted and 30% as smoked fillet. Investment costs increase by 15% to 6900 EUR/m³ PV (2.07 mil. EUR) due to the slaughtering, cooling and smoking plant. Filleting and smoking lead to an additional need of 3.91 workers/year and therefore additional costs of 112,156 EUR/year. Water costs increase by 10% and electricity costs by 15%. 64,058 kg of whole fish, 65,659 kg of fillets, 39,395 kg of smoked fillets and 151,176 kg of trimmings are produced annually.

Option 3 extends option 2 by a farm store for direct sales to final customers. The investment costs increase by another 20% to 8280 EUR/m³ PV (2.48 mil. EUR) due to the construction of a farm store including fish counter and refrigeration. In the farm store, 1.50 salesmen/year are hired for 54,250 EUR/year. Gas, electricity and water costs increase by

a further 10%. Management and administration costs increase by 50% due to increased administrative demands. Of the production, 75% is sold to wholesalers and retailers and 25% is sold directly in the farm store. In the farm store, a 75% mark-up generates sales prices of 3.85 EUR/kg (whole fish), 11.38 EUR/kg (fillet) and 21.88 EUR/kg (smoked fillet).

2.3. Calculations

The calculations were performed using Microsoft Excel® [66], with all different costs in a single output sheet. This software was chosen because, besides its simplicity, it has been used effectively for economic calculations [67]. The enterprise budget was designed to provide economic assistance to existing plant operators and companies interested in building a catfish RAS. Existing plant operators can transfer their present values and, by adjusting individual variables, evaluate which parameters need to be changed in order to maximise returns. People interested in building a RAS can find out whether the construction of a plant can be profitable under given location factors. To calculate the different entrepreneurial decision scenarios, the new values were calculated in a separate sheet and the resulting values were transferred into a separate output file. For the respective entrepreneurial decision scenarios, the formulas were adapted in each case in separate sheets. For all scenarios, the respective business figures were transferred to a separate file and used to create the related tables.

For the calculation of the return on investment (ROI) of the aquaculture units, the operating result was divided by the capital employed (net investment minus 49% subsidies), as Mecklenburg-Western Pomerania and the European Fisheries Fund (EFF) and the European Maritime and Fisheries Fund (EMFF) supported the investors with subsidies amounting to 49% of the net expenses [29] (see above). The EMFF is replaced by the European Maritime Fisheries and Aquaculture Fund (EMFAF) in 2021, which subsidises sustainable aquaculture investments up to 50% until 2027 [68]. The greenhouses of the aquaponic extension are subsidised by 20% through the agricultural investment promotion program of Mecklenburg-Western Pomerania (AFP: Agrarinvestitionsförderungsprogramm) [69].

3. Results

3.1. Initial Model

In the initial model (Table 1), the catfish farm does not generate profits, but the output based on realistic current market prices is sufficient to cover all costs. Additional benefits such as the CHP bonus, EEG reallocation charge and integration benefits into the own farming practices have not been evaluated and do not account for the aquaculture activity. The main cost driver of variable costs in the initial model is feed with a proportion of 61.42% of variable costs and 42.14% of total costs. At great distance follow the costs of energy (12.23%; 8.39%), followed by fingerlings (9.94%; 6.82%), wages (8.22%; 5.64%) and water (5.10%; 3.50%). Depreciation accounts for 22.06% of total costs.

Table 1. Yearly revenues and costs of the initial model of an African catfish farm with 300 m³ production volume with a max stocking density of 450 kg/m³ (average 180 kg/m³) and an output of 320,288 kg/year.

		Units	Price or Cost per Unit (EUR)	Quantity	Value or Costs (EUR)
Revenues					
	Whole Fish	kg	2.20	320,288	704,633
Variable Costs (VC)					
	Fish Feed	kg	1.03	288,259	296,907
	Energy				59,130 ¹
	-Gas	kWh	0.03	1,095,000	(32,850)
	-Electricity	kWh	0.08	328,500	(26,280)
	Fingerlings	each	0.20	240,216	48,043
	Wages	unit	31,000	1.2812	39,716
	Water	m ³	0.90	27,375	24,638
	Others	unit	15,000	1	15,000
Total VC					<u>483,433 ²</u>
Contribution Margin					<u>221,200</u>
Fixed Costs (FC)					
	Depreciation	unit	155,455	1	155,455
	Managing	unit	45,000	1	45,000
	Others	unit	20,745	1	20,745
Total FC					<u>221,200</u>
Total Costs (TC)					<u>704,633</u>
Returns					<u>0</u>

¹ Energy is the sum of Gas and Electricity. ² Underlines denote the sum of the respective costs.

3.2. Change in Costs and Prices

Among the main variable input factors, a change in feed has the highest impact on the key performance indicators (KPI) (Tables 2 and 3). Each ten percent change of ± 0.103 EUR/kg feed changes the returns by ± 29.691 EUR/year, the ROI by $\pm 3.23\%$ and the profit per kg of output produced by ± 0.093 EUR/kg. The percentage deviations of the KPI from the initial model are $\pm 13.42\%$ for the contribution margin (initial model: 221,200 EUR/year; 0.691 EUR/kg; new value: EUR/year; 0.783 EUR/kg), $\pm 6.14\%$ for variable costs (483,433 EUR/year; 1.509 EUR/kg) and $\pm 4.21\%$ for total costs (704,633 EUR/year; 2.200 EUR/kg). The second largest impact among the variable input factors on the changes in KPI (Table 2) is a change in energy costs. However, relative to feed, the influence of an equal percentage change in energy prices is 80% less, or the influence of energy is 20% of the influence of feed. In third place are fingerlings, which have an 84% lower influence on the KPI changes in relation to feed, followed by wages with an 87% lower influence. In last place among the variable main input factors is water with a 92% lower influence, or with only 8% of the influence of feed. The fixed costs are mainly determined by the depreciation, i.e., by the investment costs (EUR/m³ PV). Each ten percent change (± 600 EUR/m³ PV) changes the investment costs of the initial model by $\pm 180,000$ EUR and thus the depreciation and at the same time the returns by $\pm 15,546$ EUR/year. ROI changes by $\pm 1.88\%$, profit by ± 0.049 EUR/kg and total costs by $\pm 2.21\%$. Compared with feed, the impact on the changes in Table 2 is thus 48% lower for each equal-percentage change in investment costs. In the case of ROI, the impact is only 42% lower due to the exclusion of subsidies. Contribution margin and variable costs remain unaffected by changes in fixed costs. The biggest impact on the profitability is a change in the selling price. Each ten percent change (± 0.220 EUR/kg) causes a change in revenue of $\pm 70,463$ EUR/year, ROI of $\pm 7.68\%$, profit/output of ± 0.220 EUR/kg and contribution margin of $\pm 31.86\%$. Thus, the impact of the selling price on the changes in the KPI is 137% higher than that of feed. Water compared to selling price has a nearly 97% lower impact for each equal percent change. Total and variable costs remain unchanged.

Table 2. Change of key performance indicators for each ten percent change ($\pm 10\%$) in variable costs, investment costs and sales price. Returns (EUR/year), ROI (%) and Profit/Unit (EUR/kg) are total numbers. Percentage change of contribution margin (CM), variable costs (VC) and total costs (TC) shows the proportional change from the value of the initial model (EUR/year and EUR/unit).

	Unit	Change of Price or Cost/Unit (EUR)	Returns per Year (EUR/year)	ROI ¹ Total (%)	Profit per kg Fish (EUR/kg)	Percentage Change of CM (%)	Percentage Change of VC (%)	Percentage Change of TC (%)
Feed	kg	± 0.103	$\pm 29,691$	± 3.23	± 0.093	± 13.42	± 6.14	± 4.21
Energy (Total)			± 5913	± 0.64	± 0.018	± 2.67	± 1.22	± 0.84
-Gas	kWh	± 0.003	± 3285	± 0.36	± 0.010	± 1.49	± 0.68	± 0.47
-Electricity	kWh	± 0.008	± 2628	± 0.29	± 0.008	± 1.19	± 0.54	± 0.37
Fingerlings	ea.	± 0.020	± 4804	± 0.52	± 0.015	± 2.17	± 0.99	± 0.68
Wages	unit	± 3100	± 3972	± 0.43	± 0.012	± 1.80	± 0.82	± 0.56
Water	m ³	± 0.090	± 2464	± 0.27	± 0.008	± 1.11	± 0.51	± 0.35
Invest. costs	m ³ PV	± 600	$\pm 15,546$	± 1.88	± 0.049	± 0.00	± 0.00	± 2.21
Sales price	kg	± 0.220	$\pm 70,463$	± 7.68	± 0.220	± 31.86	± 0.00	± 0.00

¹ ROI = Return on Investment is calculated as returns/(investment-subsidy). Fisheries investments in Mecklenburg-Western Pomerania are subsidised at 49%.

Table 3. Impact of a ten percent reduction (-10%) in respectively one of the variable costs or investment costs or a ten percent increase ($+10\%$) in the sales price on the key performance indicators (KPIs). The initial model is the calculation basis (CB) with annual returns of 0 EUR.

	Unit	New Price or Cost/Unit (EUR)	Investment Cost (mil. EUR)	CM ² per year (EUR/Year)	Variable Costs per Year (EUR/year)	Fixed Costs per Year (EUR/Year)	Revenues per Year (EUR/Year)	Returns per Year (EUR/Year)	ROI ¹ (%)	CM ² per kg Fish (EUR/kg)	Variable Costs per kg Fish (EUR/kg)	Total Costs per kg Fish (EUR/kg)	Profit per kg Fish (EUR/kg)
Initial Model			1.80	221,200	483,433	221,200	704,633	0	0.00	0.691	1.509	2.200	0.000
Feed	kg	0.927	1.80	250,890	453,742	221,200	704,633	29,691	3.23	0.783	1.417	2.107	0.093
Energy (Total)			1.80	227,113	477,520	221,200	704,633	5913	0.64	0.709	1.491	2.182	0.018
-Gas	kWh	0.027	1.80	224,485	480,148	221,200	704,633	3285	0.36	0.701	1.499	2.190	0.010
-Electricity	kWh	0.072	1.80	223,828	480,805	221,200	704,633	2628	0.29	0.699	1.501	2.192	0.008
Fingerlings	each	0.180	1.80	226,004	478,628	221,200	704,633	4804	0.52	0.706	1.494	2.185	0.015
Wages	unit	27,900	1.80	225,171	479,461	221,200	704,633	3972	0.43	0.703	1.497	2.188	0.012
Water	m ³	0.810	1.80	223,663	480,969	221,200	704,633	2464	0.27	0.698	1.502	2.192	0.008
Invest. costs	m ³ PV	5400	1.62	221,200	483,433	205,654	704,633	15,546	1.88	0.691	1.509	2.151	0.049
Sales price	kg	2.420	1.80	291,636	483,433	221,200	775,096	70,463	7.68	0.911	1.509	2.200	0.220

¹ ROI = Return on Investment is calculated as returns/(investment-subsidy). Fisheries investments in Mecklenburg-Western Pomerania are subsidised at 49%. ² CM = Contribution Margin.

3.3. Entrepreneurial Decision Scenarios

3.3.1. Double Production Volume

By doubling production from 300 m³ to 600 m³ production volume, the variable costs per unit (VCU) of the initial model is reduced by 7.6% from 1.509 EUR/kg to 1.395 EUR/kg and the total costs per unit (CPU) is reduced by 12.4% from 2.200 EUR/kg to 1.926 EUR/kg (Table 4). With double the output, the savings generate returns of 175,240 EUR/year (0.274 EUR/kg fish) with an ROI of 11.45% (Table 5). A ten percent increase in the retail price of whole fish in this scenario results in an increase in returns and ROI of 80.4% (316,167 EUR/year; 20.66%).

3.3.2. Higher Stocking Densities

The increase in max. stocking density from 450 kg/m³ to 550 kg/m³ (average stocking density 220 kg/m³) slightly increases VCU by 1.5% to 1.532 EUR/kg and CPU is reduced by 4.7% (Table 4). The 22% increase in output (391,463 kg/year) generates returns of 40,379 EUR/year (0.10 EUR/kg) with an ROI of 4.40% (Table 5). In this scenario, a ten percent increase in the selling price leads to a 213.3% increase in returns and ROI (126,167 EUR/year; 13.78%).

Table 4. Sales price, contribution margin per unit (CMU), variable costs per unit (VCU), total costs per unit (CPU) and profit per unit (PPU) of the respective products in the different scenarios.

Scenario	Units	Sales Price (EUR/Unit)	CMU (EUR/Unit)	VCU (EUR/Unit)	CPU (EUR/Unit)	PPU (EUR/Unit)
Initial Model						
300 m ² ; 450 kg/m ³ PV	kg whole fish	2.200	0.691	1.509	2.200	0.00
Double Production Volume						
Opt. 1 (600 m ³ PV)	kg whole fish	2.200	0.805	1.395	1.926	0.274
Higher Stocking Density						
Opt. 1 (max. 550 kg/m ³)	kg whole fish	2.200	0.668	1.532	2.097	0.103
Fingerling Production						
Opt. 1 (Own Requirements)	each fingerling	0.200	0.004	0.196	0.312	−0.112
Opt. 2 (300% Fingerling Prod.)	each fingerling	0.200	0.112	0.088	0.142	0.058
Aquaponic Integration						
Aquaculture	kg whole fish	2.310	0.801	1.509	2.196	0.114
Opt. 1 (Tomato Prod.)	kg tomato	2.500	1.540	0.960	2.199	0.301
Opt. 2 (Basil Prod.)	each pot basil	0.850	0.399	0.430	0.746	0.104
Higher Value-Added Level						
Opt. 1 (Filet Prod.)	kg filet	6.500	2.042	4.458	6.189	0.311
Opt. 2 (Smoked Filet Prod.)	kg smoked filet	12.500	6.925	5.575	7.365	5.135
Opt. 3 (Direct Sales)	kg whole fish	3.850	2.147	1.703	2.648	1.202
	kg filet	11.375	6.484	4.891	7.125	4.250
	kg smoked filet	21.875	15.877	5.998	8.232	13.643

3.3.3. Fingerling Production

With fingerling production, in the case of exclusive self-supply (Opt. 1) of the farm (240,216 fingerlings/year), a fingerling has VCU of 0.196 EUR/each, CPU of 0.312 EUR/each and a PPU of −0.112 EUR/each (Table 4). Considered as a single investment, the fingerling production has an ROI of −17.65%. Despite the elimination of fingerlings costs,

the excessively high production costs result in negative returns of −27,011 EUR/year (−0.08 EUR/kg) with an ROI of −2.33% (Table 5). In option 2, the farm produces 300% of its own needs (720,647 fingerlings/year) and resells 200%. VCU are reduced by 55.3% to 0.088 EUR/each, CPU decrease by 54.7% to 0.142 EUR/each due to economies of scale (Table 4). Thus, at a selling price of 0.200 EUR/each, a saving, or PPU of 0.058 EUR/each can be achieved. Considered as a single investment, the hatchery has an ROI of 21.18%. This results in returns of 34,684 EUR/year and an ROI of 3.11% (Table 5). A ten percent increase in fingerling prices increases returns and ROI by 27.7% (44,293 EUR/year; 3,97%).

Table 5. The impact of the different scenarios on the total investment costs (TIC), and yearly variable costs (VC), fixed costs (FC), revenues, returns and return on investment (ROI). In addition, the impact of a ten percent change (+10%) in the sales price of the respective production unit on the key performance indicators in the respective scenarios is calculated. In case of price variations, TIC, VC and FC remain unchanged.

Szenario	TIC (EUR)	VC (EUR/Year)	FC (EUR/Year)	Revenues (EUR/Year)	Returns (EUR/Year)	ROI ¹ (%)
Initial Model 300 m ² ; 450 kg/m ³ PV	1,800,000	483,432	221,199	704,632	0.00	0.00%
Double Production Volume Opt. 1 (600 m ³ PV) +10% Fish Price	3,000,000	893,630	340,395	1,409,265 1,550,192	175,240 316,167	11.45% 20.66%
Higher Stocking Density Opt. 1 (max. 550 kg/m ³ PV) +10% Fish Price	1,800,000	599,639	221,200	861,218 947,339	40,379 126,501	4.40% 13.78%
Fingerling Production Opt. 1 (Own Production) Opt. 2 (300 % Fingerling Prod.) +10% Fingerling Price	2,100,000 2,190,000	482,460 505,967	249,183 260,068	704,633 800,719 810,327	−27,011 34,684 44,293	−2.52% 3.11% 3.97%
Aquaponic Integration Aquaculture Opt. 1 (1000 m ² Tomatoes) Total Aquaponic +10% Tomato Price Total Aquaponic Opt. 2 (10,000 m ² Basil) Total Aquaponic +10% Basil Price Total Aquaponic	1,890,000 509,548 2,399,548	483,433 50,880 534,313	219,972 65,690 285,662	739,864 132,500 872,364 145,750 885,614 2,018,750 2,758,614 2,220,625 2,960,489	36,459 15,930 52,389 29,180 65,639 248,043 284,502 449,918 486,377	3.78% 3.91% 3.82% 7.16% 4.79% 6.93% 6.26% 12.57% 10.70%
Higher Value-Added Level Opt. 1 (80% Filet) +10% Filet Price Opt. 2 (30% Smoked Filet, 80% Filet) +10% Smoked Filet Price Opt. 3 (Direct Sales) +10% Direct Sales Price	1,980,000 2,070,000 2,480,000	566,065 610,995 666,512	236,745 244,518 302,772	831,338 899,624 1,067,710 1,116,955 1,266,489 1,312,870	28,529 96,814 212,198 261,442 297,204 343,586	2.83% 9.59% 20.10% 24.76% 23.46% 27.12%

¹ ROI = Return on Investment is calculated as returns/(investment-subsidy). Fisheries investments in Mecklenburg-Western Pomerania are subsidised at 49% and agricultural investments (aquaponic integration option 1 and 2) at 20%.

3.3.4. Aquaponic Integration

Due to the aquaponic integration, the VCU in the fish farm remain unchanged, the CPU decrease minimally by 0.2% (Table 4). Due to the increased sales price of the aquaponically distributed fish, fish farm returns increase to 36,459 EUR/year (0.114 EUR/kg) and

ROI increases to 3.78% (Table 5). In option 1, the tomato greenhouse generates returns of 15,930 EUR/year (0.301 EUR/kg tomato) and an ROI of 3.91%. Fish and plant farming considered as a single aquaponics enterprise generate returns of 52,389 EUR/year and an ROI of 3.82%. A 10% increase in tomato prices increases returns and ROI of the greenhouse by 83.2% (29,180 EUR/year; 7.16%) and of the aquaponic enterprise by 25.3% (65,639 EUR/year; 4.79%). In option 2, the large 10,000 m² basil greenhouse generates returns of 248,043 EUR/year (0.10 EUR/pot) and an ROI of 10.87%. Together with fish farming, this results in returns of 284,502 EUR/year and an ROI of 8.76%. A ten percent increase in basil prices increases returns and ROI of the greenhouse by 81.4% (449,918 EUR/year; 12.57%) and of the aquaponic farm by 71.0% (486,377 EUR/year; 10.70%).

3.3.5. Higher Value-Added Level

In option 1, 80% of the production is filleted and 20% is sold as whole fish. The 20% whole fish (64,058 kg/year) returns 140,927 EUR/year. With a fillet yield of 41%, 105,054 kg/year of fillet are produced and generate 682,853 EUR/year. In addition, the trimmings (151 tons) contribute 7559 EUR/year, if sold outside. Possible internal use on the farms has not been considered. The total revenue of 831,338 EUR/year results in returns of 28,529 EUR/year and an ROI of 2.83% (Table 5). A ten percent increase in fillet price increases the two KPIs by 239.4% (96,814 EUR/year; 9.59%). Labour costs in this scenario increase by 195.2% to 127,027 EUR/year, with a total costs share (TC) of 15.82% (22.44% VC).

In option 2 (20% whole fish, 50% fillet, 30% smoked fillet), the 20% whole fish and the 151 tons of trimmings continue to generate 140,927 EUR/year and 7559 EUR/year, respectively. The 50% fillets (65,659 kg/year) generate 426,783 EUR/year and the 30% smoked fillets (39,395 kg/year) 492,442 EUR/year. The total revenue of 1,069,710 EUR/year leads to returns of 212,198 EUR/year with an ROI of 20.10%. If the smoked fillet price increases by 10%, both KPIs increase by 23.2% (261,442 EUR/year; 24.76%). In this scenario, labour costs increase by 423.6% compared to the initial model to 168,220 EUR/year with a significantly higher TC share of 19.66% (27.53% VC).

Option 3 extends option 2 with direct marketing to end consumers (25% of production). The marketing of 75% of the production to wholesalers and retailers generates revenues of 802,673 EUR/year. The 25% direct marketing, with selling prices of 3.85 EUR/kg (whole fish), 11.38 EUR/kg (fillet) and 21.88 EUR/kg (smoked fillet), generate 463,816 EUR/year, almost 37% of the 1,266,489 EUR/year total revenue. In total, returns of 297,204 EUR/year and an ROI of 23.46% are realised. A ten percent increase in prices in the direct marketing makes the two key figures rise by 15.6% (343,586 EUR/year; 27.12%). Labour costs increase by 440.6% to 214,720 EUR/year, ranking clearly behind feed and before energy costs with a TC share of 22.15% (32.22% VC).

4. Discussion

The present study calculates the cost structure of African catfish RAS in northern Germany based on a model farm and current market conditions. The northern German catfish aquaculture is a very young industry, which was indirectly initiated by the European Commission through the EFF 2007–2013 and EMFF 2014–2021. Subsidised fishery investments at 49% motivated farmers to enter this new sector. Along with the additional benefits of an internal use of the electricity and heat from own biogas plants, the integration into regular farming practices, the ecological sustainability of production and the CHP bonus and EEG reallocation charge, an investment in heat-utilising catfish RAS is particularly attractive. However, under the current economic market conditions for a less established fish species and due to management and fish disease-related production stoppages/shortages, the northern German catfish farms have not yet managed to achieve the promised long-term operating results. In the following, the effects of price variations and different entrepreneurial decision scenarios on key performance indicators of German catfish farms are listed and discussed.

4.1. Initial Model with Price Variation

An average African catfish RAS (recirculating aquaculture system) with a production volume of 300 m³ and an output of 320 t/year can cover all costs, but has difficulties to reach profitably (Table 1) without consideration of additional benefits (see above). The most important economic variable in African catfish RAS is the low selling price, caused by a less established market environment for this relatively unknown species. If the average selling price (2.20 EUR/kg) changes by 10%, the returns change by $\pm 70,463$ EUR/year (Table 2). The average selling price and the total production costs of 2.20 EUR/kg as well as the variable costs of 1.51 EUR/kg can be considered as critical prices. For catfish (*Ictalurus furcatus* $\times$ *Ictalurus punctatus*) split-pond aquaculture in Arkansas and Mississippi, critical price thresholds are lower with a range of 1.72–2.05 USD/kg [70] due to cheaper production in pond aquaculture and not RAS. Production costs in areas where African catfish are most economically cultivated vary from <1 USD/kg to 2.5 USD/kg [14]. The selling prices of living African catfish in sub-Saharan Africa (2.5–5.0 USD/kg), alternatively Central Africa (3.3–5.2 USD/kg) or Nigeria (3.5 USD/kg) [14], demonstrate clearly that 2.20 EUR/kg in Germany is very low for regionally produced high valuable animal proteins [23] and African catfish still has a lot of marketing potential.

In northern Germany, most of the production is sold as whole fish to wholesalers, whereby far the lowest returns are achieved compared to retail and direct marketing. The difficulty of selling larger quantities to retailers is that catfish farms are located in the most sparsely populated, agriculturally dominated regions of northern Germany, with a low incidence of retail trade. This makes it more difficult to distribute larger quantities on better price conditions. Nevertheless, the focus of the plant operators should be to build upon more retail contract partners. Slightly higher selling prices already cover the increased transportation costs and labour hours. When selling to retailers, it is important to ensure that the contractually agreed purchase quantities are adhered, otherwise there is a risk of contractual penalties. A general prognosis regarding African catfish prices is difficult to make. However, there are studies that predict a decrease in animal protein consumption and an increase especially in fish and seafood substitutes in Europe [71]. Annual per capita consumption of fish and fishery products in Germany also decreased by 19% from 2011 (15.7 kg) to 2019 (13.2 kg) [72]. After a slight increase in 2020, further decrease in consumption is predicted by 2022 [73]. From 2021 to 2026, the industry's revenue is expected to increase by 1.2%/year and the average price of fish and fishery products is expected to increase by 11.3% over the entire period [73]. These values indicate the trend direction of the German fish industry but a full extrapolation to the northern German catfish market cannot be made.

Fish feed accounts for 42.14% of the TC (total costs) and 61.42% of VC (variable costs), which is similar to catfish split-pond aquaculture in Arkansas and Mississippi, where feed accounts for 47–56% TC (54–61% VC) [70]. The returns change by $\pm 29,691$ EUR/year for each ten percent change in purchase prices (Table 2). In Nigerian pond culture, feed costs average 64% of TC [74], while in Thai and Vietnamese *Pangasius* pond culture feed costs reach 81% and 86% of TC [75], respectively, making them even more sensitive to price changes. This difference is caused by a different degree of investment costs, which is higher in RAS operations compared with pond aquaculture. Catfish feed has a protein content of at least 40% with the majority coming from fish meal. While the demand for fish meal increased, its production decreased by 26.5% from 2000–2018 due to climatic events, resulting in a price increase during the same period from 452 USD/t to 1597 USD/t [76]. Occasionally, *C. gariepinus* growers had to close their operations as high production costs exceeded the selling prices due to high feed costs [14]. In order to compensate for the resulting increase in the price of fish feed, catfish farmers must be in a position to pass on the price increases to their customers or to secure long-term price commitments from suppliers by contract. In addition, researchers and farm operators need to continue research on plant-based fish meal substitutes that are accepted by catfish and achieve better growth performance. The declining fish-in/fish-out ratio from 0.63 in 2000 via 0.33 (2010) through

to 0.22 (2015) shows the resilience of the sector for fish meal replacement [76]. It was also demonstrated that a feed additive of 0.5% 1 g557 to regular African catfish feed already resulted in a 2% (0.8–3.2%) better growth performance of juveniles, raising the returns by 4367 EUR/year including extra costs [77]. This suggests high potentials for the further development of more adequate African catfish feed in future.

The investment costs per m³ of production volume are largely determined by the farm size, structural conditions and degree of mechanisation and influence the annual operating result through depreciation. With a share of 22.06% of TC, each ten percent variation changes the returns by ±15,546 EUR/year. The catfish split-ponds in North America have very low depreciation shares of 3–6% of TC due to lower investment costs, but also have considerably more inefficient production at FCRs of 1.8–2.6 [70] compared with the northern German RAS averaging FCRs of 0.9. Energy costs are far behind feed costs, accounting for 8.39% of TC (12.23% VC). Every ten percent change in gas and electricity prices changes the returns by ±5913 EUR/year (Table 2). Since the farmers in northern Germany produce electricity and waste heat through their own biogas plants, future increases in energy costs are not considered critical. In general, the principle of on-site supply with renewable energies is not only more sustainable, but also more cost-efficient than fossil-based fuels and thus of potential use to RAS [78]. In addition, the new government elected in 2021 will promote the expansion of renewable energies [79], which makes new subsidies for biogas plants with utilisation of waste heat in the upcoming years likely. Fingerlings account for 6.82% of TC (9.94% VC) and result in a change in returns of ±4804 EUR/year for each ten percent price change. In Cameroon (0.15–0.25 USD/each) or Nigeria (0.1–0.2 USD/each), prices are also high due to high demand, causing many farmers to prefer collecting wild seed with poor growth performance [14]. In terms of cost, this variable is considered less critical for German farmers, but nevertheless a part of the production is still dependent on fingerlings from the Netherlands. In the case of supply shortages of Dutch producers, it can be assumed that Dutch bulk buyers will be preferred over the northern German catfish farms, which could lead to production bottlenecks. This could in turn jeopardise the supply of customers in the lucrative retail trade due to contractual quantities that cannot be met. In order to be less dependent on foreign suppliers, a stable regional catfish hatchery producing high quality fingerlings must be established in the medium term.

Wages represent 5.64% of TC (8.22% VC) for a highly mechanised plant without hand slaughtering. Each ten percent price variation changes the returns by ±3972 EUR/year. In the case of internal hand slaughtering and filleting or a lower level of automation, labor costs increase and they should be considered in more detail. Since mainly unskilled labor is hired for repetitive tasks, payments at or slightly above statutory minimum wage are common. In this context, it should be noted that Germany is planning a successive increase in minimum wages in the coming years, especially with the new government [80,81]. Above a certain labor wage, it may be reasonable to dispense with hand slaughtering and outsource this activity or to invest into a filleting machine. Water costs amount to 3.50% of TC (5.10% VC) and change returns by ±2464 EUR/year for each ten percent change. Since all northern German catfish RAS already have their own wells for industrial water production, further costs can be saved by reducing the price of drinking water and wastewater. The price of drinking water can hardly be influenced and depends on regional conditions and internal consumption in sanitary facilities and slaughtering. Wastewater costs, on the other hand, can be reduced by irrigation on own fields or by further use in hydroponic cultivations (aquaponics).

The list demonstrates that the main focus for African catfish farmers in northern Germany must be on improving sales prices and reducing feed costs in order to run the RAS profitably. The ROI shows that despite the deduction of subsidies only in the scenario of a price increase the ROI already reaches an attractive value (7.86%). Although there are economically more interesting investment objects, from the sustainability perspective and in the light of the current climatic development, regional food production in Europe is to be evaluated as an indispensable future supply model. For this reason, the EMFF, which

expired in 2020, was replaced in 2021 by the EMFAF (European Maritime, Fisheries and Aquaculture Fund) [68], which runs until 2027. This will continue to support aquaculture projects at 50%, allowing investments to remain attractive under the right conditions. In addition, it aims to support and form “producer organisations”. A producer organisation in northern Germany for the joint creation of synergies and utilisation of resources is assessed as imperative. Thus, joint bulk purchase deals for feed could be closed in order to significantly reduce costs and also to develop an own feed production in the long term. Furthermore, a regional fingerling hatchery could be created in order to produce the entire regional demand cost-efficiently and to achieve independence from Dutch suppliers. In addition, know-how could be exchanged and human resources shared, or investments could be made in jointly used machinery and equipment such as a filleting machine. Furthermore, larger contracts with retail chains could be concluded jointly, as it would be easier to meet contractually agreed purchase quantities at agreed times. This would result in a significant price increase. Moreover, investments could be made in marketing campaigns that increase the image and popularity of the African catfish, thus increasing its demand and sales price. For the establishment, the competitive thinking of the individual actors and personal interests must be overcome, and action plans must be drawn up together with research institutions.

4.2. Entrepreneurial Decision Scenarios

Entrepreneurial decision scenarios on the economics of catfish aquaculture are analysed in order to envision future potential for this industry. A RAS twice as large (600 m³ PV) as in the initial model (300 m³ PV) is modelled, which saves costs through economies of scale. In a large plant, the fish can be produced at lower CPU 1.926 EUR/kg and VCU 1.395 EUR/kg which enhance the PPU to 0.274 EUR/kg (Table 4). Returns of 175,240 EUR/year and an ROI of 11.45% are achieved (Table 5). With a 10% increase in the catfish price to 2.42 EUR/kg, returns and ROI increase by 80.4% (316,167 EUR/year; 20.66%) and would transform a catfish RAS into an attractive investment. A model study of the profitability of U.S. pond, raceway, and RAS aquaculture showed that RAS systems were not profitable at any size or with any species, but larger systems showed fewer losses (in USD/kg) than smaller systems [32]. The study found economies of scale for all species/systems/sizes studied, which is consistent with observed trends of generally increasing farm size in aquaculture. The present results show that new investments into larger sized RAS are highly recommended in order to further develop the northern German catfish aquaculture into a profitable business sector. It is advisable to divide larger farms into two or more hygienically separated halls in order to avoid the loss of the entire stock in the event of a disease outbreak.

The scenario of increasing the maximum stocking densities from 450 kg/m³ to 550 kg/m³ increases the VCU slightly (1.532 EUR/kg) but decreases the CPU (1.926 EUR/kg) due to a better utilisation of the production capacities, thus achieving a PPU of 0.103 EUR/kg (Table 4). This results in returns of 40,379 EUR/year and an ROI of 4.40% (Table 5). Although high stocking densities result in improved profitability, the likelihood of filter and pipe clogging and critical water levels being exceeded is increased. In addition, not all available feeds are suitable for RAS aquaculture and increase nutrient and total suspended matter loads and malfunctioning of biofilters. Therefore, more frequent water monitoring and filter cleaning must be carried out. High stocking densities also promote heterogeneous fish growth, resulting in uneven fillet sizes when slaughtered by hand and high discard rates when slaughtered by machine [20]. Mortality rates and also the FCR of African catfish in commercial RAS can slightly increase with increasing stocking density from extensive (FCR 0.96/0.87–1.14) to intensive (0.99/0.94–1.07) over the entire production cycle [9]. Superintensive stocking densities can be seen as questionable from an animal ethics point of view and can affect sales through negative publicity.

The entrepreneurial decision to produce own fingerlings is divided into two options. The first option of self-sufficiency is not recommended because the extra costs of

the higher skilled employee and the investment costs for the hatchery are significantly higher than the savings. However, a hatchery can be profitable if production exceeds own requirements. Thus, by producing 300% of the own requirements (option 2), the CPU (0.141 EUR/each) and VCU (0.088 EUR/each) are approximately halved and the PPU improves from −0.090 EUR/each to 0.059 EUR/each (Table 4). Besides the returns of 39,871 EUR/year (Table 5), the biggest benefit is the independence from external suppliers. An increase in the costs of fingerlings would have only a minimal impact on the KPIs. The critical price threshold for fingerlings in this scenario is 0.128 EUR/fish. If this threshold is undercut at the same output a negative operating result will be achieved again. Among the main problems of own fingerling production, besides high mortality rates and high feed costs [82], there is still a lack of know-how for efficient breeding of healthy fingerlings, as successful hatcheries keep their know-how as company secret. To overcome this knowledge gap, companies need to work closely with research institutions to establish the best possible protocols for seedling production in future.

The scenario of aquaponics integration through a large-scale greenhouse is a critical economic decision. In addition to high investment costs, a greenhouse opens another economic sector with completely different products and requires additional know-how and distribution channels. In the first option, a 1000 m² tomato greenhouse is integrated. Aquaponic tomato production can be operated commercially and produce marketable fruit if mineral fertilisers are added and the cycles are decoupled, i.e., the fertilised process water from the plants is not recirculated to the fish [65]. Aquaponic tomato cultivation can increase fertilisation efficiency by 23.6% compared to hydroponic cultivation [65], but the demand for fertilisation is still high. In the case of tomatoes, the main benefits of aquaponic production are improved marketing opportunities of both fish and plants. The increased sales prices improve the aquaculture KPIs (returns 36,459 EUR/year; ROI 3.78%) and achieve, together with the greenhouse (returns 15,930 EUR/year; ROI 3.91%), returns of 52,389 EUR/year and an ROI of 3.82% (Table 5). A study in the U.S. Midwest found that aquaponics systems require higher investment and operating costs and concurrently lower crop production than hydroponics systems, and only become profitable with a 20% premium price [83]. A 10% increase in tomato prices would increase the returns and ROI by 25.3% (65,639 EUR/year; 4.79%). Option 2 integrates a highly productive 10,000 m² basil greenhouse with artificial lighting for year-round production. Basil has already achieved promising results in aquaponics [24]; only small amounts of additional fertilisation, especially with potassium and iron, would be necessary [25,26]. The greenhouse (returns 248,502 EUR/year; ROI 6.93%) together with aquaculture would result in returns of 284,502 EUR/year and an ROI of 6.26%. In 2015, an international survey reported that of 257 aquaponics farms surveyed, of which 188 were classified as “commercial-scale”, less than one-third were profitable in the past year [84]. However, the average commercial production site in the US in this study was only 100 m² of cultivation area and a water volume of 10.3 m³ [84], suggesting that a large proportion of respondents were more likely to be classified as small-scale/semi commercial (≤ 100 m²) [64]. There are contradicting views of aquaponics profitability, but there is consensus that larger systems are economically superior to smaller ones and that profitability depends on retail prices [85]. The integration of a smaller greenhouse is financially viable if the marketing effect spikes higher fish prices. A ten percent increase in basil prices would increase aquaponics KPIs by 71% (returns 486,377 EUR/year; ROI 10.70%). For a production of over 2 million pots, an increase in basil prices would primarily be realised through a larger number of retail customers. In the structurally weak northeast of Germany, this is associated with considerably higher transport costs. Furthermore, an integration on this scale is associated with enormous investment costs of several million euros. Larger investments could become interesting especially if European sustainability funds would also subsidise aquaponic investments with 50%. Aquaponic systems have created a strong public perception of sustainable, regional food production. Aquaponic integration would improve the publicity of the company and create a positive customer experience when buying aquaponic products. In order to

use the marketing advantages most efficiently, the aquaponic principle including fresh plants should be publicly visible for the customers and an additional farm store should be integrated where the end-consumer can buy the fresh products with mark-ups of significantly more than 10%. Since aquaponics is a young field of science, there is still a lot of potential for development, especially with regard to increasing productivity. A particularly productive system for aquaponic basil cultivation has proven to be “aeroponics”, a system where the roots grow in the air and are sprayed with process water from the fishes [26].

The last scenario of the higher value-added level is divided into three options. In option 1, hand slaughtering is integrated and 80% of the production is sold as fillet. At an average fillet price of 6.50 EUR/kg, the company generates still relatively unattractive KPIs with returns of 28,529 EUR/year with an ROI of 2.83% due to high labour costs (Table 5). However, the higher value of filleting becomes apparent when the fillet price increases due to higher sales to retailers and end-consumer. A ten percent increase in fillet price to 7.15 EUR/kg increases the two KPIs significantly by 239.4% and turns the farm into a lucrative business (96,814 EUR/year; 9.59%). An entrepreneur must calculate at what output the investment in an automated slaughter machine is worthwhile. The advantages for this would be the saving of wages and the identical trimming production. The disadvantages are high investment costs and poorer processing of heterogeneously grown fish. Another option to increase added value is incorporation of additional benefits, because the fish farm can be integrated into the regular farming practices, such as the biogas (CHP, EEG), animal husbandry, crop production and plant irrigation during summer. If a conventional pig fattening is part of the corporation, the ensiled trimmings can be added to the pig feed. The valuable nutrients of the carcass are profitably reused, but only a certain amount can be processed and added to the pig feed (<10%), otherwise the pigs reject the feed. Accordingly, a larger pig fattening is required to fully utilise the trimmings. The remaining trimmings are sold far below value (50 EUR/t) to fish meal plants in Cuxhaven, where most of the added value takes place. If poorly planned, disposal to rendering plants (40–100 EUR/t) or biogas plants (10–12 EUR/t) may even incur costs [86]. In order to shift the added value to Mecklenburg-Western Pomerania, the farms would have to chemically ensile or deep-freeze their trimmings and process them centrally (in cooperation) into fish meal or use them directly for the production of dry feed pellet.

In option 2, 30% of the production is processed into smoked fillets and 50% into fillets. As smoking is one of the highest processing stages of fish products in northern Germany, the high prices (12.50 EUR/kg) can already generate very lucrative returns of 212,198 EUR/year and an ROI of 20.10%. If the smoked fillet price increases by 10%, returns and ROI increase by 23.2% (261,442 EUR/year; 24.76%). In the European trout market, smoked trout accounted for 307 mil. EUR, more than the half of the total intra-EU trade flow (590 mil. EUR.) in 2020 [87]. The main importer among the member states was Germany (308 mil. EUR), with a share of 81% smoked products (249 mil. EUR). Of the global fish and seafood revenue (455.2 bil. USD), processed products accounts for only 28% and fresh products 55%, which can be justified by the high share of Asia (293.6 bil. USD), where consumers prefer fresh products [88]. A 2011 analysis of the Egyptian aquaculture value chain concluded that the industry is (i.a.) under increasing financial pressure due to a lack of processing and exports, caused by distrust of processed/filleted products. [89]. The figures demonstrate that processing is one of the most important parts of the European value chain, which inevitably has to be generated internally within the company or inside the country. The third option extends option 2 by a farm store where 25% of the total production is sold and direct marketing prices lead to a mark-up of 75%. Despite the additional costs, the company can already generate returns of 297,204 EUR/year and a lucrative ROI of 23.46%. If the farm store can increase prices by another 10%, the two KPIs increase by 15.6% (343,586 EUR/year; 27.12%). The farm store could also generate sales by trading additional fishery and agricultural products. The difficulty is that the catfish farms are located in the structurally weakest regions in the northeast of Germany and farm stores integrated in the farm location might not have sufficient clientele to sell 25% of the

production. The development of more remote farm stores in areas with higher purchasing power, such as Rostock, Schwerin or Greifswald, could be more profitable, but would incur further costs.

The results from the entrepreneurial decision scenarios show with the background of a 50% subsidy from the new European fund (EMFAF) that investments remain attractive. Especially by implementing the right entrepreneurial decisions, the industry can become a profitable economic sector. Since a large proportion of the fishery value chain is created in processing, in addition to filleting, higher levels of processing such as smoking should be targeted within the company. To improve sales prices, larger quantities must be distributed to retailers and end-consumer.

5. Conclusions

The farmland-based model catfish farm in northern Germany with an output of 320 t/year is currently gainless but economically viable, without consideration of additional benefits. The biggest impact on the profitability of the farm is the selling price, with each ten percent change changing the returns by ± 70.463 EUR/year. Among the variable costs, feed has the main impact and accounts for 42.14% of TC and 61.42% of VC. This is much lower compared with already analysed pond aquaculture systems where feed can reach 86% of TC. Each ten percent change in feed price results in a change of returns of ± 29.691 EUR/year, followed in descending order by energy (10% price change changes returns by ± 5.913 EUR/year), fingerlings (± 4.804 EUR/year), wages (± 3.972 EUR/year), and water (± 2.464 EUR/year), which together account for only 24.35% of TC (35.49% of VC). If the investment costs can be reduced by 10%, the operating result will change by ± 15.546 EUR/year due to lower depreciation.

Different entrepreneurial decision scenarios have significant impact on profitability. A plant size with double the production output can achieve attractive returns of 175,240 EUR/year and an ROI of 11.45%. If the whole fish price increases by 10%, these two ratios increase by 80.4% (316,167 EUR/year; 20.66%). This suggests a larger investment if the investors have sufficient capital available. An increase of the maximum stocking density to 550 kg/m³ may increase the ROI by 4.40%, but risks system malfunctioning and bad publicity. An own fingerling production does not make sense in the case of an exclusive self-supply due to high labour costs, but economically turns positive if three times of the own demand is produced and 200% is resold to regional breeders. An aquaponic integration of a 1000 m² tomato greenhouse could result in returns and an ROI of the entire complex of 52,389 EUR/year and 3.82%. A 10,000 m² greenhouse with LED lighting for the year-round cultivation of basil, could generate 284,502 EUR/year and an ROI of 6.26%, together with fish farming. The main advantage of aquaponic farming is the principle of sustainable food production, with higher selling prices, reduced waste and reuse of water. Further strategies to enhance the profitability of northern German catfish aquaculture are to keep the added value within the company by increasing the processing stages.

Investments by northern German farmers in catfish aquaculture remain promising due to possible 50% subsidies of the EMFAF funding program. The farms must ensure that the plants not only contribute to the regional food supply, but also operate economically sustainable. The variable costs of 1,51 EUR/kg can be considered as critical, and investors must consider that also for aquaculture in rural areas larger systems (approx. 600 m³ PV) are significantly more profitable. Farm sizes of about 300 m³ PV are more price sensible and dependent on larger distribution volumes to retailers and end customers. Additional synergies can be generated through the establishment of a regional “producer organisation”. Together with possible improvements of feed and cultivation techniques together with increasing fish prices, African catfish farms in northern Germany still have large potential for improvement, turning this economically viable aquaculture into an ecological and economical sustainable highly profitable business.

Author Contributions: All authors contributed to several aspects of the study, specifically, conceptualisation: J.P. and H.W.P.; methodology: J.P. and H.W.P.; software: J.P.; validation: J.P. and H.W.P.; formal analysis: J.P.; investigation: J.P. and H.W.P.; resources: J.P. and H.W.P.; data curation: J.P. and H.W.P.; writing—original draft preparation: J.P.; writing—review and editing: J.P. and H.W.P.; visualisation: J.P.; supervision: H.W.P.; project administration: H.W.P.; funding acquisition: H.W.P. All authors have read and agreed to the published version of the manuscript.

Funding: We thank the Ministry of Agriculture, Environment and Consumer Protection of Mecklenburg-Western Pomerania (Germany), the European Union and EIP-AGRI operational groups for supporting research in aquaponics ('Aquaponik in MV', BNRZD: 13 903 000 0103; WM-EIP-0007-15). This project was supported in part through the project "Performance and process water management in commercial (integrated) aquaculture systems with African catfish (*Clarias gariepinus*) in Mecklenburg-Western Pomerania" (MV-II.1-LM-007: 139030000103, EMFF: 7302). This project was also supported by the Steinbeis-Transferzentrum Aquakultur and the Ph. D Scholarship Programme "Unsere Besten promovieren in Rostock" (JP) from the University of Rostock. We thank regional African catfish producers in MV for providing information and highly valuable discussions. We acknowledge financial support from Deutsche Forschungsgemeinschaft and Universität Rostock within the funding programme Open Access Publishing.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The authors follow MDPI's Data Availability Statement.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. FAO. *FishStatJ v4.01.1 (October 2021)*; FAO: Rome, Italy, 2021.
2. Tacon, A.G.J. Trends in Global Aquaculture and Aquafeed Production: 2000–2017. *Rev. Fish. Sci. Aquac.* **2020**, *28*, 43–56. [CrossRef]
3. FAO. *The State of World Fisheries and Aquaculture 2020. Sustainability in Action*; FAO: Rome, Italy, 2020; p. 206.
4. Bundesministerium für Ernährung und Landwirtschaft (BMEL). *Jahresbericht zur Deutschen Binnenfischerei und Binnenaquakultur 2019*; BMEL: Bonn, Germany, 2021; p. 61.
5. European Commission. *European Green Deal: Commission Adopts Strategic Guidelines for Sustainable and Competitive EU Aquaculture*; European Commission: Brussels, Belgium, 2021; p. 2.
6. Badiola, M.; Mendiola, D.; Bostock, J. Recirculating Aquaculture Systems (RAS) analysis: Main issues on management and future challenges. *Aquac. Eng.* **2012**, *51*, 26–35. [CrossRef]
7. Martins, C.I.; Schrama, J.W.; Verreth, J.A. The effect of group composition on the welfare of African catfish (*Clarias gariepinus*). *Appl. Anim. Behav. Sci.* **2006**, *97*, 323–334. [CrossRef]
8. EUMOFA, European Commission. *Recirculating Aquaculture Systems*; Publications Office of the European Union: Luxembourg, 2020; p. 45.
9. Palm, H.; Knaus, U.; Wasenitz, B.; Bischoff, A.; Strauch, S. Proportional up scaling of African catfish (*Clarias gariepinus* Burchell, 1822) commercial recirculating aquaculture systems disproportionally affects nutrient dynamics. *Aquaculture* **2018**, *491*, 155–168. [CrossRef]
10. Asche, F.; Guttormsen, A.G.; Nielsen, R. Future challenges for the maturing Norwegian salmon aquaculture industry: An analysis of total factor productivity change from 1996 to 2008. *Aquaculture* **2013**, *396–399*, 43–50. [CrossRef]
11. Jokumsen, A.; Svendsen, L.M. *Farming of Freshwater Rainbow Trout in Denmark*; DTU Aqua Report no. 219-2010; DTU Aqua, National Institute of Aquatic Resources: Charlottenlund, Denmark, 2010; p. 47.
12. Summerfelt, S.T.; Davidson, J.; May, T.; Good, C.; Vinci, B. Emerging trends in salmonid RAS—Part II. System enhancements. *Glob. Aquac. Adv.* **2015**, *18*, 64–65.
13. FAO.org. Available online: https://www.fao.org/fishery/culturedspecies/Sander_luciperca/en (accessed on 27 October 2021).
14. FAO.org. Available online: https://www.fao.org/fishery/culturedspecies/Clarias_gariepinus/en (accessed on 28 October 2021).
15. Schmidt-Puckhaber, B. *Fisch vom Hof?!: Fischerzeugung in Standortunabhängigen Kreislaufanlagen*, 1st ed.; DLG-Verlag: Frankfurt, Germany, 2010; p. 144.
16. Statistisches Bundesamt (Destatis). *Land und Forstwirtschaft, Fischerei. Erzeugung in Aquakulturbetrieben*; Fachserie 3, Reihe 4.6, 2018; Statistisches Bundesamt (Destatis): Wiesbaden, Germany, 2019; p. 54.
17. Hengsawat, K.; Ward, F.; Jaruratjamorn, P.P. The effect of stocking density on yield, growth and mortality of African catfish (*Clarias gariepinus* Burchell 1822) cultured in cages. *Aquaculture* **1997**, *152*, 67–76. [CrossRef]
18. Hossain, M.A.; Beveridge, M.C.; Haylor, G.S. The effects of density, light and shelter on the growth and survival of African catfish (*Clarias gariepinus* Burchell, 1822) fingerlings. *Aquaculture* **1998**, *160*, 251–258. [CrossRef]

19. van de Nieuwegiessen, P.G.; Olwo, J.; Khong, S.; Verreth, J.; Schrama, J. Effects of age and stocking density on the welfare of African catfish, *Clarias gariepinus* Burchell. *Aquaculture* **2009**, *288*, 69–75. [CrossRef]
20. Pasch, J.; Appelbaum, S.; Knaus, U.; Sandmann, P.; Palm, H.W. Effects of stocking density of African catfish (*Clarias gariepinus*) life stages in RAS on growth performance and profitability. *Aquaculture*, under review.
21. Roques, J.A.C.; Schram, E.; Spanings, T.; van Schaik, T.; Abbink, W.; Boerrigter, J.; de Vries, P.; van de Vis, H.; Flik, G. The impact of elevated water nitrite concentration on physiology, growth and feed intake of African catfish *Clarias gariepinus* (Burchell 1822). *Aquac. Res.* **2015**, *46*, 1384–1395. [CrossRef]
22. Schram, E.; Roques, J.A.; Abbink, W.; Spanings, T.; de Vries, P.; Bierman, S.; van de Vis, H.; Flik, G. The impact of elevated water ammonia concentration on physiology, growth and feed intake of African catfish (*Clarias gariepinus*). *Aquaculture* **2010**, *306*, 108–115. [CrossRef]
23. Wasenitz, B.; Karl, H.; Palm, H.W. Composition and quality attributes of fillets from different catfish species on the German market. *J. Food Saf. Food Qual.* **2018**, *69*, 57–65.
24. Knaus, U.; Pribbernow, M.; Xu, L.; Appelbaum, S.; Palm, H.W. Basil (*Ocimum basilicum*) cultivation in decoupled aquaponics with three hydro-components (grow pipes, raft, gravel) and African catfish (*clarias gariepinus*) production in Northern Germany. *Sustainability* **2020**, *12*, 8745. [CrossRef]
25. Pasch, J.; Ratajczak, B.; Appelbaum, S.; Palm, H.; Knaus, U. Growth of Basil (*Ocimum basilicum*) in DRF, Raft, and Grow Pipes with Effluents of African Catfish (*Clarias gariepinus*) in Decoupled Aquaponics. *AgriEngineering* **2021**, *3*, 6. [CrossRef]
26. Pasch, J.; Appelbaum, S.; Palm, H.; Knaus, U. Growth of Basil (*Ocimum basilicum*) in Aeroponics, DRF, and Raft Systems with Effluents of African Catfish (*Clarias gariepinus*) in Decoupled Aquaponics (s.s.). *AgriEngineering* **2021**, *3*, 36. [CrossRef]
27. Knaus, U.; Wenzel, L.; Appelbaum, S.; Palm, H. Aquaponics (s.l.) Production of Spearmint (*Mentha spicata*) with African Catfish (*Clarias gariepinus*) in Northern Germany. *Sustainability* **2020**, *12*, 8717. [CrossRef]
28. Oladimeji, S.A.; Okomoda, V.T.; Olufeagba, S.O.; Solomon, S.G.; Abol-Munafi, A.B.; Alabi, K.I.; Ikhwanuddin, M.; Martins, C.O.; Umaru, J.; Hassan, A. Aquaponics production of catfish and pumpkin: Comparison with conventional production systems. *Food Sci. Nutr.* **2020**, *8*, 2307–2315. [CrossRef] [PubMed]
29. EC.europa.eu. Available online: https://ec.europa.eu/oceans-and-fisheries/funding/european-maritime-and-fisheries-fund-emff_en (accessed on 27 October 2021).
30. Umweltbundesamt.de. Available online: <https://www.umweltbundesamt.de/themen/klima-energie/erneuerbare-energien/erneuerbare-energien-gesetz#erfolg> (accessed on 27 October 2021).
31. BMWI.de. Available online: <https://www.bmwi.de/Redaktion/DE/Artikel/Energie/moderne-kraftwerkstechnologien.html> (accessed on 27 October 2021).
32. Engle, C.R.; Kumar, G.; Van Senten, J. Cost drivers and profitability of U.S. pond, raceway, and RAS aquaculture. *J. World Aquac. Soc.* **2020**, *51*, 847–873. [CrossRef]
33. Xiao, R.; Wei, Y.; An, D.; Li, D.; Ta, X.; Wu, Y.; Ren, Q. A review on the research status and development trend of equipment in water treatment processes of recirculating aquaculture systems. *Rev. Aquac.* **2019**, *11*, 863–895. [CrossRef]
34. Heiderscheidt, E.; Tesfamariam, A.; Pulkkinen, J.; Vielma, J.; Ronkanen, A.-K. Solids management in freshwater-recirculating aquaculture systems: Effectivity of inorganic and organic coagulants and the impact of operating parameters. *Sci. Total Environ.* **2020**, *742*, 140398. [CrossRef]
35. Gibson, T.F.; Watanabe, W.O.; Losordo, T.M.; Whitehead, R.F.; Carroll, P.M. Evaluation of chemical polymers as coagulation aids to remove suspended solids from marine finfish recirculating aquaculture system discharge using a geotextile bag. *Aquac. Eng.* **2020**, *90*, 102065. [CrossRef]
36. Villar-Navarro, E.; Garrido-Pérez, C.; Perales, J.A. The potential of different marine microalgae species to recycle nutrients from recirculating aquaculture systems (RAS) fish farms and produce feed additives. *Algal Res.* **2021**, *58*, 102389. [CrossRef]
37. Yogeve, U.; Vogler, M.; Nir, O.; Londong, J.; Gross, A. Phosphorous recovery from a novel recirculating aquaculture system followed by its sustainable reuse as a fertilizer. *Sci. Total Environ.* **2020**, *722*, 137949. [CrossRef] [PubMed]
38. Chen, Z.; Chang, Z.; Qiao, L.; Wang, J.; Yang, L.; Liu, Y.; Song, X.; Li, J. Nitrogen removal performance and microbial diversity of bioreactor packed with cellulosic carriers in recirculating aquaculture system. *Int. Biodeterior. Biodegradation* **2021**, *157*, 105157. [CrossRef]
39. Ruiz, P.; Vidal, J.M.; Sepúlveda, D.; Torres, C.; Villouta, G.; Carrasco, C.; Aguilera, F.; Ruiz-Tagle, N.; Urrutia, H. Overview and future perspectives of nitrifying bacteria on biofilters for recirculating aquaculture systems. *Rev. Aquac.* **2019**, *12*, 1478–1494. [CrossRef]
40. Jiang, W.; Tian, X.; Li, L.; Dong, S.; Zhao, K.; Li, H.; Cai, Y. Temporal bacterial community succession during the start-up process of biofilters in a cold-freshwater recirculating aquaculture system. *Bioresour. Technol.* **2019**, *287*, 121441. [CrossRef] [PubMed]
41. Rojas-Tirado, P.A.; Pedersen, P.B.; Pedersen, L.-F. Bacterial activity dynamics in the water phase during start-up of recirculating aquaculture systems. *Aquac. Eng.* **2017**, *78*, 24–31. [CrossRef]
42. Ekawati, A.W.; Ulfa, S.M.; Dewi, C.S.U.; Aziz, A.; Amin, L.N.M.S.; Yanuar, A.T.; Kurniawan, A. Analysis of Aquaponic-Recirculation Aquaculture System (A-Ras) Application in the Catfish (*Clarias gariepinus*) Aquaculture in Indonesia. *Aquaculture* **2021**, *21*, 93–100. [CrossRef]
43. Supjaruwong, S.; Satanwat, P.; Pungrasmi, W.; Powtongsook, S. Design and function of a nitrogen and sediment removal system in a recirculating aquaculture system optimized for aquaponics. *Environ. Eng. Res.* **2020**, *26*, 190494. [CrossRef]

44. Calone, R.; Pennisi, G.; Morgenstern, R.; Sanyé-Mengual, E.; Lorleberg, W.; Dapprich, P.; Winkler, P.; Orsini, F.; Gianquinto, G. Improving water management in European catfish recirculating aquaculture systems through catfish-lettuce aquaponics. *Sci. Total Environ.* **2019**, *687*, 759–767. [CrossRef]
45. O'Rourke, P.D. The economics of recirculating aquaculture systems. In Proceedings of the 1st International Conference on Recirculating Aquaculture, Virginia Polytechnic Institute and State University, Roanoke, VA, USA, 20–23 July 1996; pp. 1–19.
46. Aich, N.; Nama, S.; Biswal, A.; Paul, T. A review on recirculating aquaculture systems: Challenges and opportunities for sustainable aquaculture. *Innov. Farming* **2020**, *5*, 17–24.
47. Ngoc, P.T.A.; Meuwissen, M.P.M.; Tru, L.C.; Bosma, R.H.; Verreth, J.; Lansink, A.O. Economic feasibility of recirculating aquaculture systems in pangasius farming. *Aquac. Econ. Manag.* **2016**, *20*, 185–200. [CrossRef]
48. Om, A.D.; Yusoff, N.H.N.; Jamari, Z. Evaluation of economics feasibility on marine fish seeds nursed in local backyard re-circulating aquaculture system (RAS). *Int. J. Fish. Aquat. Stud.* **2020**, *8*, 288–293.
49. Ranjan, R.; Megarajan, S.; Xavier, B.; Raju, S.S.; Ghosh, S.; Gopalakrishnan, A. Design and performance of recirculating aquaculture system for marine finfish broodstock development. *Aquac. Eng.* **2019**, *85*, 90–97. [CrossRef]
50. de Souza Motta, J.H.; Vidal Júnior, M.V.; Glória, L.S.; Cruz Neto, M.A.; Silveira, L.S.D.; Andrade, D.R.D. Technical and economic feasibility of food strategies in the hatchery of *Cyprinus carpio* (*Cypriniformes*, *Cyprinidae*) in a recirculating aquaculture system. *Latin Am. J. Aquat. Res.* **2019**, *47*, 626–637.
51. Kristan, J.; Blecha, M.; Policar, T. Survival and growth rates of juvenile Grass Carp *Ctenopharyngodon idella* overwintered in ponds and recirculating aquaculture systems including a comparison of production economics. *Turk. J. Fish. Aquat. Sci.* **2018**, *19*, 261–266.
52. Pereira, D.A.S.; Henriques, M.B. Economic feasibility for producing Imperial Zebra pleco (*Hypancistrus zebra*) in recirculating aquaculture systems: An alternative for a critically endangered ornamental fish. *Aquac. Econ. Manag.* **2019**, *23*, 428–448. [CrossRef]
53. Mohammad, T.; Moulick, S.; Mukherjee, C.K. Economic feasibility of goldfish (*Carassius auratus* Linn.) recirculating aquaculture system. *Aquac. Res.* **2018**, *49*, 2945–2953. [CrossRef]
54. Diatin, I.; Shafruddin, D.; Hude, N.; Sholihah, M.; Mutsmir, I. Production performance and financial feasibility analysis of farming catfish (*Clarias gariepinus*) utilizing water exchange system, aquaponic, and biofloc technology. *J. Saudi Soc. Agric. Sci.* **2021**, *20*, 344–351. [CrossRef]
55. Oké, V.; Goosen, N. The effect of stocking density on profitability of African catfish (*Clarias gariepinus*) culture in extensive pond systems. *Aquaculture* **2019**, *507*, 385–392. [CrossRef]
56. Oluwalola, O.; Fagbenro, O.; Adebayo, O. Growth and Economic Performances of African Catfish, *Clarias gariepinus* Reared under Different Culture Facilities. *Afr. J. Fish. Aquat. Resour. Manag.* **2019**, *4*, 75–84.
57. Asche, F.; Roll, K.H.; Tveteras, R. Economic inefficiency and environmental impact: An application to aquaculture production. *J. Environ. Econ. Manag.* **2009**, *58*, 93–105. [CrossRef]
58. El-Sayed, A.-F.; Dickson, M.; El-Naggar, G.O. Value chain analysis of the aquaculture feed sector in Egypt. *Aquaculture* **2015**, *437*, 92–101. [CrossRef]
59. Guttormsen, A.G. Input Factor Substitutability in Salmon Aquaculture. *Mar. Resour. Econ.* **2002**, *17*, 91–102. [CrossRef]
60. Coppens.de. Available online: https://static.alltechcoppens.com/assets/DE_CATFISH_2021.pdf?mtime=20210209101004&focal=none (accessed on 28 October 2021).
61. Coppens.de. Available online: <https://www.alltechcoppens.com/de/aktuelles/farming-catfish-in-ras> (accessed on 28 October 2021).
62. KTBL.de. Available online: <https://www.ktbl.de/webanwendungen/baukost-gewaechshaeuser> (accessed on 28 October 2021).
63. KTBL.de. Available online: <https://www.ktbl.de/webanwendungen/gemuese-im-geschuetzten-anbau> (accessed on 28 October 2021).
64. Palm, H.W.; Knaus, U.; Appelbaum, S.; Goddek, S.; Strauch, S.M.; Vermeulen, T.; Jijakli, M.H.; Kotzen, B. Towards commercial aquaponics: A review of systems, designs, scales and nomenclature. *Aquac. Int.* **2018**, *26*, 813–842. [CrossRef]
65. Suhl, J.; Dannehl, D.; Kloas, W.; Baganz, D.; Jobs, S.; Scheibe, G.; Schmidt, U. Advanced aquaponics: Evaluation of intensive tomato production in aquaponics vs. conventional hydroponics. *Agric. Water Manag.* **2016**, *178*, 335–344. [CrossRef]
66. Microsoft® Corporation. *Microsoft Excel®*; Microsoft Corporation: Redmond, WA, USA, 2010.
67. Benker, H. Excel in der Wirtschaftsmathematik. In *Excel in der Wirtschaftsmathematik*, 1st ed.; Benker, H., Ed.; Springer: Wiesbaden, Germany, 2014; Volume 1, pp. 93–97.
68. EC.europa.eu. Available online: https://ec.europa.eu/oceans-and-fisheries/funding/emfaf_en (accessed on 28 October 2021).
69. Service.m-v.de. Available online: https://www.service.m-v.de/foerderfibel/?sa.fofi.foerderung.foerderung_id=24&sa.fofi.kategorie_id=1 (accessed on 28 October 2021).
70. Kumar, G.; Engle, C.; Tucker, C. Costs and Risk of Catfish Split-pond Systems. *J. World Aquac. Soc.* **2016**, *47*, 327–340. [CrossRef]
71. Morach, B.; Witte, B.; Walker, D.; von Koeller, E.; Grosse-Holz, F.; Rogg, J.; Brigl, M.; Dehnert, N.; Obloj, P.; Koktenturk, S.; et al. Food for Thought: The Protein Transformation. *Ind. Biotechnol.* **2021**, *17*, 125–133. [CrossRef]
72. Statista.com. Available online: <https://de.statista.com/statistik/daten/studie/1905/umfrage/entwicklung-des-pro-kopf-verbrauchs-an-fisch-in-deutschland/> (accessed on 28 October 2021).
73. Statista.com. Available online: <https://de.statista.com/outlook/cmo/lebensmittel/fisch-meeresfruechte/deutschland#vertriebskanale> (accessed on 28 October 2021).

74. Omobepade, B.P.; Adebayo, O.T.; Amos, T.T.; Adedokun, B.C. Profitability analysis of aquaculture in ekiti state, Nigeria. *Niger. J. Agric. Food Environ.* **2015**, *11*, 114–119.
75. Hasan, M.R. On-farm feeding and feed management in aquaculture. *FAO Aquac. Newsl.* **2010**, *45*, 48.
76. Jannathulla, R.; Rajaram, V.; Kalanjiam, R.; Ambasankar, K.; Muralidhar, M.; Dayal, J.S. Fishmeal availability in the scenarios of climate change: Inevitability of fishmeal replacement in aquafeeds and approaches for the utilization of plant protein sources. *Aquac. Res.* **2019**, *50*, 3493–3506. [\[CrossRef\]](#)
77. Palm, H.W.; Berchtold, E.; Gille, B.; Knaus, U.; Wenzel, L.C.; Baßmann, B. Growth and Welfare of African catfish (*Clarias gariepinus* Burchell, 1822) under dietary supplementation of the mixed layer clay mineral montmorillonite–illite/muscovite (1g557) in commercial aquaculture. *Aquaculture* **2021**, under review.
78. Badiola, M.; Basurko, O.C.; Piedrahita, R.; Hundley, P.; Mendiola, D. Energy use in Recirculating Aquaculture Systems (RAS): A review. *Aquac. Eng.* **2018**, *81*, 57–70. [\[CrossRef\]](#)
79. Gruene.de. Available online: <https://www.gruene.de/artikel/wahlprogramm-zur-bundestagswahl-2021> (accessed on 26 November 2021).
80. DGB.de. Available online: <https://www.dgb.de/themen/++co++6ca263de-fb0e-11e9-bdcf-52540088cada> (accessed on 28 October 2021).
81. SPD.de. Available online: <https://www.spd.de/aktuelles/detail/news/mindestlohn-von-12-euro-notwendig-und-richtig/14/09/2021/> (accessed on 28 October 2021).
82. Nyonje, B.M.; Opiyo, M.A.; Orina, P.S.; Abwao, J.; Wainaina, M.; Charo-Karisa, H. Current status of freshwater fish hatcheries, broodstock management and fingerling production in the Kenya aquaculture sector. *Livest. Res. Rural. Dev.* **2018**, *30*, 1–8.
83. Quagrainie, K.K.; Flores, R.M.V.; Kim, H.-J.; McClain, V. Economic analysis of aquaponics and hydroponics production in the U.S. Midwest. *J. Appl. Aquac.* **2018**, *30*, 1–14. [\[CrossRef\]](#)
84. Love, D.C.; Fry, J.P.; Li, X.; Hill, E.S.; Genello, L.; Semmens, K.; Thompson, R.E. Commercial aquaponics production and profitability: Findings from an international survey. *Aquaculture* **2015**, *435*, 67–74. [\[CrossRef\]](#)
85. Greenfeld, A.; Becker, N.; McIlwain, J.; Fotedar, R.; Bornman, J.F. Economically viable aquaponics? Identifying the gap between potential and current uncertainties. *Rev. Aquac.* **2019**, *11*, 848–862. [\[CrossRef\]](#)
86. Valbuena, I.; Bechstein, F.; Erdös, A.; Müller-Belecke, A.; Donath, W.; Kaufhold, S. *Konzeptstudie zur Erzeugung von Trockenfuttermitteln aus Konservierten Nebenprodukten der Süßwasserfischverarbeitung und deren Verwertung Durch Karnivore Wirtschaftsfischarten*; DBU: Osnabrück, Germany, 2012; p. 76.
87. EUMOFA, European Commission. *Case Study, Portion Trout in the EU, Price Structure in the Supply Chain*; Publications Office of the European Union: Luxembourg, 2021; p. 58.
88. Frimpong, J. *Fish & Seafood Report 2021*; Statista: Hamburg, Germany, 2021; p. 34.
89. Macfadyen, G.; Nasr-Alla, A.M.; Al-Kenawy, D.; Fathi, M.; Hebicha, H.; Diab, A.M.; Mohamed, S.; Ramadan, H.; Abou-Zeid, M.; El-Naggar, G. Value-chain analysis—An assessment methodology to estimate Egyptian aquaculture sector performance. *Aquaculture* **2012**, *362*, 18–27. [\[CrossRef\]](#)