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Final Report:

The Tanganyika Aquahub (TTA)

Proof of technical and economic concept of a PV solar-powered and resource efficient fish farm input production facility

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Contents

1. Summary

In Tanzania, >70% of the population have no access to electricity. This hinders the development of many business activities especially in rural areas. This has also been the case for the upstream fish farming value chain where a steady electricity supply is necessary for water pumping and fish feed and fingerling production. The lack of electricity access is a major reason why the Tanzanian aquaculture sector has not been able to take off and cope with the rising demand for fish which is driven by the fast-growing population (60 million people in 2020 to an estimated 130 million in 2050) and the declining wild fish catches. Despite steadily rising fish prices, the fish farming sector is still at an infant stage and its production accounts for less than 2% of the fish consumption in the country.

The Tanganyika Aquahub (TTA) is a project initiated by a public-private consortium of Swiss and Tanzanian organizations with the goal to foster the use of solar PV and resource efficiency in the fish farming sector in Lake Tanganyika region in Tanzania. During the REPIC project an off-grid, solar PV powered fish farm was constructed and started operations in Kipili, a remote village next to Lake Tanganyika. The facility focuses on production of endemic Tanganyika Tilapia fingerlings (baby fish) as well as fish feed and table-sized Tanganyika Tilapia.

During the REPIC project TTA has set up a total of 13’700 Watt peak solar PV systems to operate the fish farm 100% with solar PV and without batteries. The established systems include a solar powered water supply system, a solar powered feed mill and a solar powered hatchery.
The implementation of the solar powered water supply system was able to cut water supply costs by 74% compared to a diesel generator powered pumping system. Thereby, the achieved LCOE of the solar water supply system stands at 13 cents/kWh and the average daily pumped volume of water from Lake Tanganyika to the fish ponds reached 166’000l.
With the solar powered small scale feed mill TTA was able to cut down fish feed costs from 1.05 USD to 0.55 USD per kg of fish feed. Thereby, locally unused agricultural by-products such as rice bran can be upcycled to valuable fish feeds and thereby substantially increase the resource efficiency along the value chains. The established solar feed mill uses solar-direct-drive technology to be able to operate without the use of any batteries.
Through the establishment of the solar powered hatchery, TTA has been able to cut down fingerling costs for nearby farmers by 35% from >11 cents per fingerling from Zambia to ~7 cents per fingerling from TTA. The recirculating incubator and tray system of the hatchery thereby has to be supplied with water around the clock. This is achieved with the installation of large header tanks which are filled during the day with a solar powered pump and can then supply water during the night without the use of batteries.

Further, TTA has developed the AQUASMART concept, which includes a prototype of a digital tool to operate a fish farm solely with solar PV. AQUASMART thereby uses online weather forecast data to predict future solar PV production and water pumping capacity. To achieve this, the tool uses machine learning models trained on historical online weather data and PV solar water pump data that was collected during the REPIC project. Using a week-ahead online weather forecast, AQUASMART was able to predict future weekly water pumping capacities on the fish farm with an average accuracy of 90%.

To multiplicate the efforts of the TTA REPIC project, the consortium has already started several follow up initiatives. Firstly, the goal is to scale up The Tanganyika Aquahub and expand the facility with a solar powered ice machine to build an ice-based fish distribution network that enables TTA and smallholder fish farmers to sell the farmed fish to higher priced urban markets. Secondly, a multiplication project has already started in the northern part of Lake Tanganyika with the establishment of Tanganyika Blue. Tanganyika Blue is the first commercial cage aquaculture farm in Tanzania at Lake Tanganyika. The facility will build on the learnings from TTA and implement the developed energy and resource efficiency concept including AQUASMART. Thirdly, the TTA project partners have started the development of a massive open online course (MOOC) on sustainable aquaculture in the tropics. The course will focus on energy and resource efficient fish farming operations and use TTA as a case study to give thousands of students a tangible insight into the establishment and operation of such a facility.

2. Starting Point

Lake Tanganyika is the most voluminous (18'900 km^3) tropical freshwater lake in the world. It covers an area of ~33'000km^2 (equal to over ¾ of Switzerland) and contains around 17% of the world's liquid, surface freshwater. With over 2000 species (~500 endemic) the lake is considered one of the biodiversity hotspots in the world. The current >10 million population around the lake is growing at a yearly rate between 2.0-3.2%. In recent decades, the wild fish stocks and catches from the lake have been decreasing due to climate change (inhibiting nutrient cycling in the lake) and fisheries malpractices. This has created a gap in fish supply that endangers food security. Aquaculture (=fish farming) has high potential to close this gap and increase local farmer incomes around Lake Tanganyika. However, the development of the sector is constrained by two major factors:

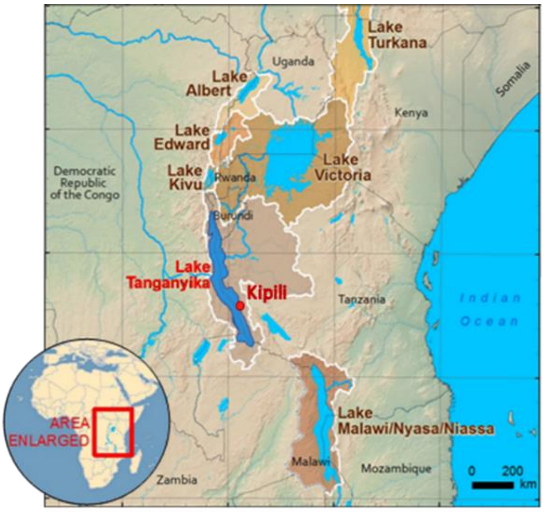


Figure 1: Lake Tanganyika and location of Kipili (Picture from The Nature Conservancy 2020).

1. **Lack of access to electricity:** One of the major reasons why smallholders cannot take up fish farming in Lake Tanganyika region is the lack of reliable electricity supply. A reliable source of electricity is especially necessary to produce the fish farming inputs (fish feed and fingerlings) and for general water management/supply of fish farms.
2. **Lack of access to fish farming inputs:** Currently farmers do not have access to fish farming inputs as there is no regional supplier of fingerlings (baby fishes) and fish feeds, one of the major reasons is as explained the lack of reliable electricity supply.

The Tanganyika Aquahub (TTA) is a project initiated by a public-private consortium of Swiss and Tanzanian organizations with the goal to foster the use of solar PV and resource efficiency to develop the fish farming sector in Lake Tanganyika region. The project is located in Kipili at Lake Tanganyika in Tanzania. Through the support of REPIC, TTA was able to implement an innovative energy- and resource efficiency concept to tackle the two major constraints of lacking access to electricity and fish farming inputs. The facility acts as a model solar-powered fish farm and already lead to several replication and multiplication projects.

3. Objectives

The three project objectives of the TTA REPIC project were:

1. Achieve economic & technical feasibility of the solar PV powered fish farming facility
2. Achieve economic & technical feasibility of TTA pond production (grow out & hatchery)
3. Achieve economic & technical feasibility of smallholder fish farming production

An overview of the project objectives and the used measured metrics and benchmarks as well as the project achievements of the objectives are outlined in Table 2.

4. Project Review

4.1 Project Implementation

4.1.1 Project Plan

The TTA REPIC project was implemented from 01st May 2021 until 30th April 2023. The project was implemented in 5 work packages (WP).

WP1: Solar PV fish farm establishment (Q2-21 to Q3-22)
Establishment of
- pond fish farm & hatchery (~3200m² pond area)
- solar PV water supply system (6.6kWp)
- solar PV recirculating hatchery system (400Wp)
- solar PV feed mill (~6.7kWp)

WP2: Energy concept (Q4-21 to Q1-23)
- Operational assessment of whole solar PV facility
- Development of the AQUASMART Concept to predict solar PV production using online weather forecasts
- Testing of the solar PV facility for 9 months with continuous monitoring

WP3: Resource efficiency concept for fish feed and fish production (Q2-21 to Q1-23)
- Two grow out cycles in TTA fish ponds using commercial fish feeds to produce table-sized Tanganyika tilapia
- Tanganyika tilapia broodstock population establishment
- Starting fingerling production using the broodstock population

WP 4: Smallholder aquaculture production with PV pumping solutions
- Farmer trainings and workshops to introduce potential stakeholders to fish farming
- Support of 2 smallholder farmers with supply of inputs
- Testing of Ennos pump for the application in smallholder fish farming

WP 5: Multiplication & Scale-up
- Development of TTA business and expansion plans
- Started multiplication project in Northern part of Lake Tanganyika with the establishment of Tanganyika Blue, the first commercial Tanzanian cage culture farm at Lake Tanganyika, incl. energy & resource efficiency concepts and AQUASMART developed during REPIC project
- Attracted further public and private (!) financing for TTA and replication/multiplication projects during the REPIC project in the range of 400k USD
- Started Development of MOOC for tropical aquaculture incl. use of renewable energies and resource efficiency concepts

Figure 2: From top to bottom: Fish pond construction, solar panels of the water supply system, hatchery building with incubator & tray system and solar PV roofing, inverter and switches of the solar powered feed mill

4.1.2 Challenges & Adjustments

Considering the challenges around the COVID-19 pandemic and resulting impacts on the global and regional economy, the REPIC project could be implemented without major modifications of the initial project plan. However, some challenges led to minor modifications in the project implementation:
- Change of initial layout of the farm from ~6'000m² to 3'200m² of pond area due to price hikes in equipment (up to +40%) and fish feed (up to +50%), to ensure liquidity and successful completion of the REPIC project
- Establishment of the solar feed mill and production of farm-made feeds were delayed by 12 months, due to various challenges: supply chain disruptions delayed procurement of equipment

(mill equipment, additional motors, solar-direct-drive inverter), solar-direct-drive setup more complicated and expensive than expected (e.g. exchange of mill motors to cope with variable frequency of the system), further also delayed due to massive order book from the contracted solar company in Tanzania (after reopening of the economy after COVID, numerous projects needed to get going again at once)

- Lightning strike next to solar water supply system in Q1-22 destroyed the controller and with it collected data of the PV and pump system. Afterwards we switched to an online monitoring system that measures and collects data in real time and stores the data in a cloud.
- After extensive consultation with community stakeholders, the strategy on smallholder fish farmer outreach was changed from providing full support (including pond building costs, fish feed and fingerling costs) to 6 potential fish farmers to 'only' partial support with training and supply of fingerlings to selected people (2 during the REPIC project duration) that had already started farming on their own. In the long term this form of outreach (training, creating awareness, coaching) will be more sustainable than subsidizing smallholder fish farming operations. However, the new approach also led to delays in reaching the project objectives.
- First sales of fish from the TTA operation have shown that one of the constraints in fisheries and fish farming development in the region is the lack of cold chains. Kipili is around 150km away from the next larger city (Sumbawanga: population of ~150k). To be able to supply the 'retail' market and achieve higher sales prices (e.g. butcheries with freezers etc.) a cold chain is necessary. Therefore, it was decided to implement a solar powered ice machine at the TTA facility to be powered by a solar PV direct drive system (together with feed mill PV system incl. AQUASMART). The ice will help to market TTA's produce and also the produce of the smallholder fish farmers in the region through the planned outgrower model (sales of fingerlings and fish feed to smallholder farmers and buyback & distribution of grown fish).

4.1.3 Project Partners & Responsibilities

TTA was initiated by a public private partnership of 6 Tanzanian and Swiss institutions (c.f. Table 1).

Overall project coordination was done by SUSTAIN Switzerland with ZHAW in co-lead.

Table 1: TTA partners, institutions, project responsibilities and activities

Institution & Description	Project Responsibilities & Activities
SUSTAIN (CH): SUSTAIN Switzerland GmbH is a Swiss venture builder company focusing on the sustainable development of aquaculture value chains in East Africa. TTA is a portfolio venture of SUSTAIN.	• Lead of REPIC project, mgmt & coordination • Farm and operations planning incl. solar PV • Development of AQUASMART concept • Project reporting incl. financials • Multiplication
Zurich University of Applied Sciences (CH): The aquaculture group of ZHAW has extensive experience in tropical aquaculture research & development in various fields	• Co-lead of REPIC project • Training materials (smallholders & internal) • Farm management capacity building, farm SOPs • Develop. of MOOC in tropical fish farming
The Spring Project (CH): TSP is a Swiss association that supports sustainable projects around the globe.	• Raising of funds • Reporting to funders
Lake Shore Lodge (TZ): LSL is a tourist lodge in Kipili, operating solely on solar PV, with ~30 FTE and an experienced management team. LSL is the main implementing partner of TTA.	• Project implementation • TTA management & operations • HR • Accounting
Bongo Samaki (TZ): BOS is a Tanzanian company that empowers people to start their own profitable fish farm.	• Initial farm management and capacity building • Smallholder training & coaching
Tanzania Fisheries Research Institute (TZ): TAFIRI is the national fisheries and aquaculture research institute. TAFIRI has a branch in Kigoma at Lake Tanganyika.	• Feeding trials and R&D • Preparing publications

4.2 Achievements of Objectives and Results

4.2.1 Achievements of Objectives

Table 2 shows the objectives of the TTA REPIC project and the respective metrics incl. benchmarks and the achievements during the project.

Table 2: TTA REPIC project objectives with the respective metrics / benchmarks and the achieved outcomes

Obj.	Description	Metrics & Benchmark	TTA REPIC achievements
1	Achieve economic & technical feasibility of PV powered fish farming facility	LCOE per unit of production, business case Costs in diesel powered facility, PV system with battery storage	'Effective'[1] LCOE for solar PV water supply system: 0.13 USD/kWh 'Effective'[1] LCOE for solar PV hatchery: 0.19 USD/kWh 'Theoretical'[2] LCOE for solar PV feed mill: 0.12 USD/kWh
2	Achieve economic & technical feasibility of TTA pond production (grow out & hatchery)	Production costs per unit (USD/kg tilapia, USD/fingerling) Production costs with feed & fingerlings from nearest supplier (Zambia), TZ market prices	Production costs: Tanganyika tilapia whole: 2.4 USD/kg (min.), 5 USD/kg (max, but mismanaged) Tanganyika tilapia fingerlings: sales price to smallholder farmers at ~7 cents per piece Fish feed: 0.55 USD/kg (grow out feed)
3	Achieve economic & technical feasibility of smallholder solar PV fish farming production	Production costs, opportunity costs, income increase Local & regional fish market prices, current farmer incomes	Production costs of smallholders: range from 2 USD/kg to 4 USD/kg (sparse recording) Local fish prices: Tanganyika tilapia min. 1.3 USD/kg (smaller sized fish), max. 2.2 USD/kg (>250g fish). Regional fish prices (away from lake coast): min. 3.0 USD/kg to 4.8 USD/kg

4.2.2 Results

4.2.2.1 Solar PV fish farm establishment

Establishment costs

The establishment costs (setup costs excluding construction equipment, short-term assets and advisory etc.) were in line with expectations for the construction of the ponds (0% deviation) and the solar hatchery (-1% deviation), above expectations for the solar water supply systems (+29%) and below expectations for the solar feed mill (-28%). The overall establishment costs for the solar systems and the ponds (excluding costs for other buildings) were according to the initially outlined budget (-1%).

Table 3: Construction costs of the TTA facilities (excluding office building, warehouse and housing)

System	Expected establishment costs	Actual establishment costs	Actual vs. Expected
Ponds (3'200 sqm)	CHF 30'625	CHF 30'805	0%
Solar Water Supply	CHF 19'120	CHF 24'662	+29%
Solar Hatchery	CHF 15'008	CHF 14'845	-1%
Solar Feed Mill	CHF 23'424	CHF 16'899	-28%
Total	CHF 88'177	CHF 87'211	-1%

1 Effective LCOE: unit cost of used energy (not only production)
2 Theoretical LCOE: unit cost of produced energy (even if not all could be used)

Centralized vs. decentralized PV systems
After consulting with various PV contractors in TZ and choosing Power Providers Limited for the establishment of the water supply and feed mill systems, we decided to establish 3 separate PV systems and not one central system as initially planned.
This due to the following reasons:

- The contractor (Power Providers Limited) is an experienced and approved sales and service partner of LORENTZ; the PS2-4000 C-SJ17-4 was selected as the most suitable pumping solution (appropriate capacity and efficiency at 35m static head, high quality product within budget), furthermore, Lorentz provides sophisticated monitoring tools for their equipment (data logging etc.) which was necessary for the development of the AQUASMART Concept.
- The pump and solar feed are 500m apart, using a centralized PV system would add cabling costs
- Input voltage of the feed mill SSD system (>600V) differs from the solar pump (>238V)
- Small solar DC pumps suitable for the recirculating incubator system become more and more available. Using such a separate system is cheaper and easier scalable than linking a common (AC) pumping solution to a central PV system incl. inverter. The ennos sunlight pump was used in the hatchery system as it entails a data logging tool for the development of the AQUASMART Concept.

Solar system and appliances specification

Table 4, and Table 6 show the system specifications of the 3 established solar systems and respective appliances. One of the key aspect is the battery free operation of all systems, which was achieved with direct-drive technology and smart water storage.

Table 4: Solar water supply system with an integrated real-time online data logging tool

The solar water supply system pumps water from Lake Tanganyika to the fish ponds of The Tanganyika Aquahub	
Pump Brand	Lorentz
Model	PS2-4000 C-SJ17-4
Type	Submersible pump
Power	max. 4.0 kW
Solar PV Modules Brand	JA Solar
Power per Panel [Wp]	315
Number of panels	21
Total PV Power [Wp]	6615
Horizontal pumping distance [m]	500
Pipe	100mm HDPE, PN10
Geostatic head [m]	32
Optimum input Voltage [V]	>238
Data logging	Online
Other	Data logging in real-time, accessible for download through a portal, measuring the following parameters in 10min intervals: water flow, power, voltage, current, speed, controller temp, irradiation, motor current

Table 5: Battery free, solar-direct-drive (SSD) system to power the feed mill

The solar feed mill consists of a solar powered hammer mill and pelletizer which are used to produce farm made feeds at TTA. The solar panels for the solar feed mill system are further used as roofing for the hatchery building.	 
Machines	Hammer mill, pelletizer
Motors	Standfoot 4kW (pelletizer) & 5.5 kW (hammer mill), both 3 phase
Mode of operation	separately, one machine at the time
Solar Direct Drive	Emponi, 5.5 kW
Solar PV Modules Brand	Suntech
Power per Panel [Wp]	445
Number of panels	15
Total PV Power [Wp]	6675
Optimum input Voltage [V]	>600
Data logging	No
Other	Customized solar-direct-drive system to allow battery-free operation of the feed mill machines

Table 6: Solar powered hatchery water supply system to operate the incubator and tray system

The solar powered hatchery consists of a solar powered water pump, 20’000l header tanks, incubator and tray system and a 20’000l sump	 
Pump Brand	Ennos
Model	Sunlight
Type	Surface pump
Power	0.5 HP
Power per Panel [Wp]	85
Number of panels	4
Total PV Power [Wp]	340
Horizontal pumping distance [m]	21
Pipe	2’’
Geostatic head [m]	4-5m (depending on water level in sump)
Data logging	Bluetooth & mobile app, no data export option
Other	Supply of the incubator and tray system with running water 24/7 through pumping of water during the day into 20’000l of storage tanks to allow battery free operation during the night

4.2.2.2 Energy concept

Solar water supply system

The solar water supply system has been pumping water reliable every day since its breakdown due to the lightning strike in Q1-22. In July 2022 a data acquisition tool was installed which uploads real-time data to an online platform. Collected data since then showed that the overall pumped water volume has been above expectations (Table 7).

Table 7: Actual vs. Expected monthly average pumped water volume at TTA (Lake Tanganyika to TTA ponds). Expected values were previously calculated using the Lorentz pump sizing tool, actual values were collected by built-in system sensors and online data tool from July 2022 until May 2023.

Year	Month	Expected average water flow [m^3/day]	Actual average water flow [m^3/day]	Actual vs. Expected
2022	July	167	178	+7%
2022	August	168	201	+20%
2022	September	159	188	+18%
2022	October	151	182	+21%
2022	November	140	144	+3%
2022	December	133	140	+5%
2023	January	135	156	+15%
2023	February	141	155	+10%
2023	March	144	145	+1%
2023	April	147	171	+16%
2023	May	155	182	+18%
Average		151	166	+10%

Table 8: Comparing the expected monthly average solar PV yield of the 6615Wh solar water supply PV system and actual solar pump power usage. Expected solar PV yield was calculated using the Global Solar Atlas (accessed 21.11.2020). Solar pump power usage data was collected by built-in system sensors and the online data tool. Data was collected from July 2022 until May 2023.

Year	Month	Expected average solar PV yield [kWh/day]	Actual solar pump power usage [kWh/day]	Ratio of actual solar pump power usage / expected solar PV yield
2022	July	36	23	-36%
2022	August	36	25	-30%
2022	September	34	23	-32%
2022	October	33	22	-32%
2022	November	27	17	-34%
2022	December	25	17	-32%
2023	January	25	19	-24%
2023	February	25	19	-23%
2023	March	31	18	-43%
2023	April	31	21	-31%
2023	May	35	23	-34%
Average		31	21	-33%

The ratio between the actual solar pump power usage and the expected solar PV yield was lower than -20% during all months (Table 8) which indicates that not all of the electricity that could potentially be produced by the PV system can be used by the pump. This is due to the limited power output of the pump (set to optimum of ~3.4kW). Figure 3 shows the measured pump power (‘Power [kW] (measured)’) and water flow (‘Flow [m^3/h] (measured)) during one day (data from 18.08.2022) and also indicates the theoretically possible solar PV yield from the solar system which cannot be used because of the maximum power level of the pump (‘Estimated potential PV yield not used due to max. pump power level [kW]’). The initial idea of the AQUASMART Concept was to make use of this unused electricity by e.g. powering the feed mill or ice machine with the excess electricity. However, this would have meant that one central solar PV system would had to be established and not separate systems. Due to various reasons as indicated previously, the decision was made to go for standalone systems.

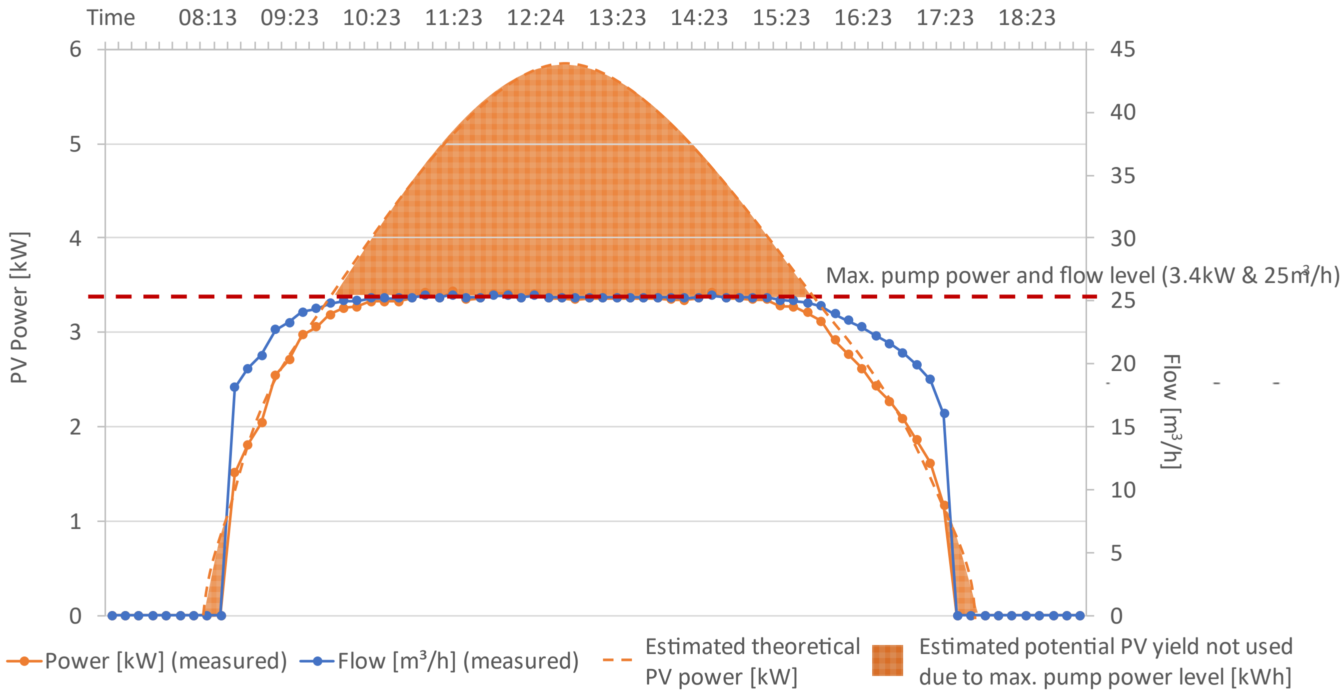
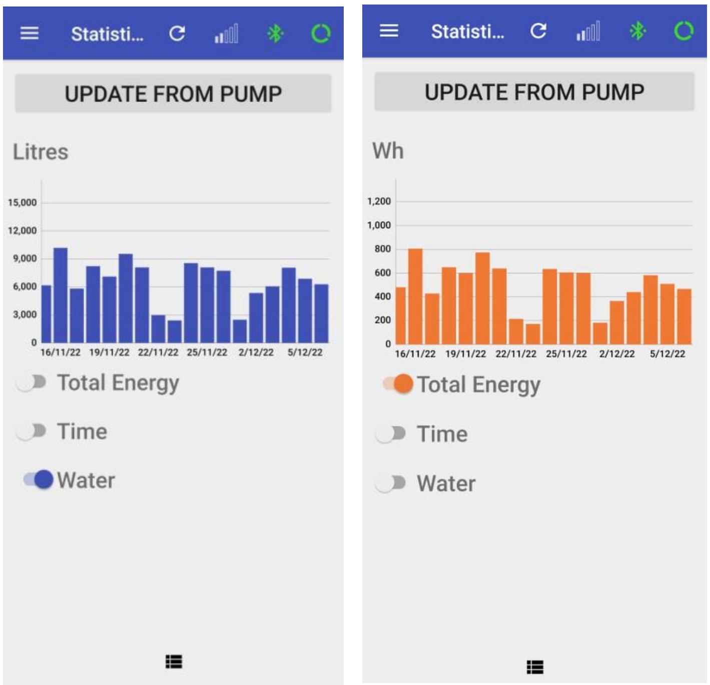


Figure 3: Data collected from the solar water supply system on 18.08.2022 including modelled theoretical PV power of the 6615 Wp system. Orange shaded area indicates an estimate for the amount of potential PV production that is lost.

Solar hatchery system

The solar hatchery system has worked very reliably since its establishment at project start. However, during the rainy season, the daily pumped water amount was not always enough to supply the optimal amount of water to the incubator system. This was compensated by decreasing the flow on the prior days (according to the AQUASMART Concept) and ensuring full header water tanks at the start of the rainy days. Data collection from the solar hatchery pump has been infrequent. This mostly because the mobile application of the pump does not allow to download the data and the flow and PV production have therefore been estimated from screenshots of the mobile application using an external application (Figure 4).



Date	Wh	Litres
15/11/2022	474	6140
16/11/2022	795	10175
17/11/2022	428	5789
18/11/2022	634	8246
19/11/2022	581	7018
20/11/2022	757	9561
21/11/2022	627	7982
22/11/2022	206	2895
23/11/2022	161	2368
24/11/2022	611	8596
25/11/2022	596	8070
26/11/2022	589	7632
27/11/2022	168	2281
28/11/2022	0	0
29/11/2022	0	0
30/11/2022	0	0
01/12/2022	0	0
02/12/2022	352	5263
03/12/2022	428	6053
04/12/2022	566	8070
05/12/2022	497	6754
06/12/2022	451	6228

Figure 4: Example of data collected of the solar hatchery pump through the Ennos pump sensors (cf. bar charts left and middle), bar charts converted to data table (c.f. excel data table on the right) with the PlotDigitizer Online App (https://plotdigitizer.com/app).

Solar feed mill

After initial challenges during the establishment, the solar-direct-drive feed mill system and its machines have now been working well since end of 2022. However, the production capacity of the hammer mill turned out to be lower than initially expected. This was because of the smaller mesh size (<1mm) that had to be used to achieve the necessary fine grain size to improve the feed quality. This increased the milling time because of high-oil content ingredients such as the groundnuts and the soya, which had to be used as oil-extruded cakes of those ingredients were not locally available. High oil contents leads to clumping during milling which limits the input amount of raw ingredients at a time and therefore extends the overall milling duration.

Table 9: Actual versus expected production capacities of the solar feed mill machines. The actual capacity was estimated with measured time usage and produced feeds during early 2023.

Machine	Expected production [kg/h]	Actual production [kg/h]	Actual vs. Expected
Hammer mill	80	45	-44%
Pelletizer	70	65	-7%

AQUASMART Concept

The goal of the AQUASMART Concept is to be able to operate the TTA or similar off-grid fish farming facilities solely with solar PV and without the use of expensive and unsustainable battery packs.
One of the major constraints of being dependent on solely solar energy is its inconsistent and unpredictable power supply. This is especially a challenge when managing a fish farm's water supply. AQUASMART will solve this by providing predictions on future daily water flow from the solar water supply system obtained through machine learning models.
Figure 5 shows the AQUASMART machine learning pipeline. The initial input data consists of historical modelled online weather data and historical weather forecast data obtained from OpenWeather. Further, historical PV water pumping data is used (from the TTA solar water supply system). These three data sources are then cleansed and processed into training & testing data to develop the machine learning model. In a next step, these datasets are then used to choose the most suitable machine learning model by looping through several types of models and input parameters that can be provided in CSV format. The training data is thereby used to train each model and with the testing data evaluation metrics are then obtained. Used models were linear regression, random forest (RF), gradient boosting algorithms (GBM) and artificial neural networks (ANN).

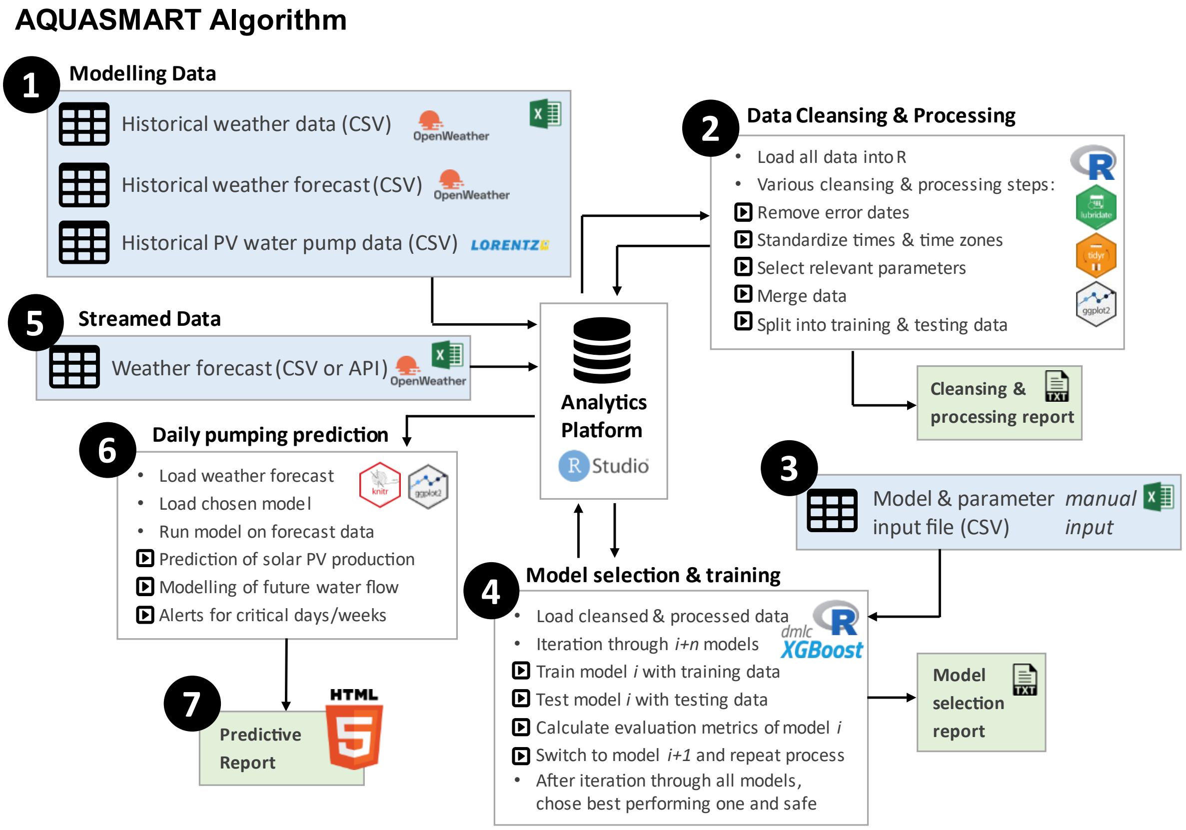


Figure 5: The data pipeline of the AQUASMART algorithm with highlighted input data (blue boxes), data engineering & analytics steps (white boxes) and report outputs (green boxes)

After choosing the model and suitable model parameters, the latest weather forecast data is then fed into AQUASMART and predictions for future solar PV production and water flow are modelled with the machine learning model. This then allows to plan ahead for the water supply of the fish farm and take necessary actions e.g. such as decreasing feeding ahead of low water flow volumes.
The red bars in Figure 6 show the actual weekly flow rates of the TTA water supply system from week 31 to week 50 in 2022. The green bars thereby depict the weekly predicted flow obtained from the AQUASMART algorithm using weekly weather forecasts (forecast made Monday 00:00 for the coming week) as input data. The AQUASMART concept thereby reached an accuracy of 90% using weekly online weather forecasts.

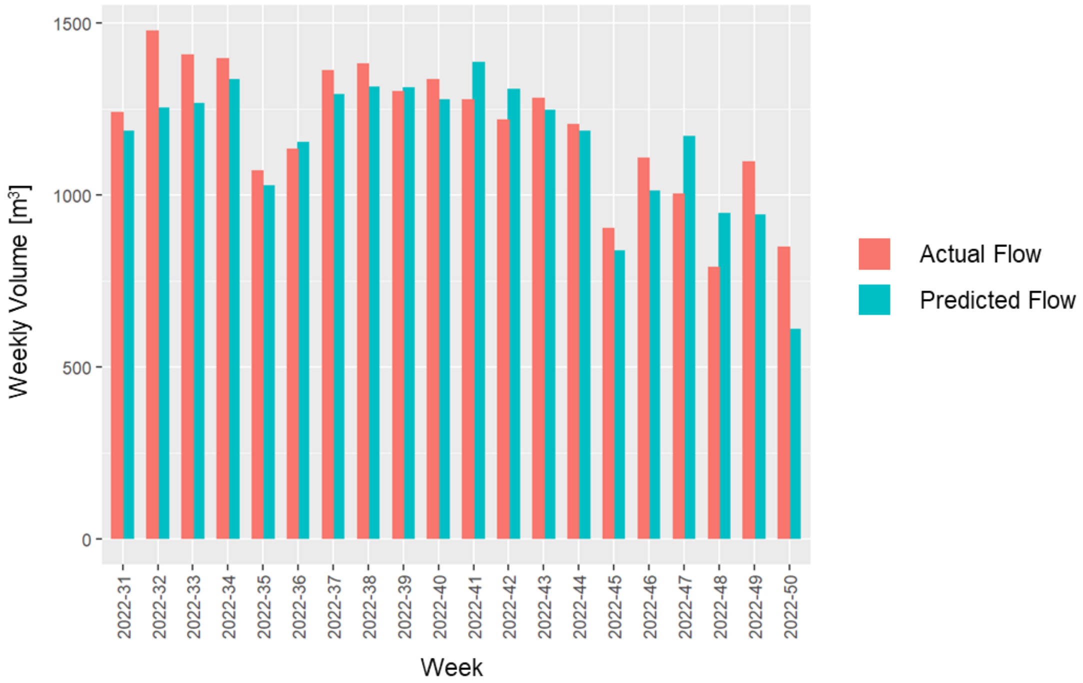


Figure 6: Prediction of weekly water flow at TTA with the AQUASMART algorithm using weekly weather forecasts

4.2.2.3 Resource efficiency concept for fish feed and fish production

During the REPIC project two grow out production cycles in the TTA ponds were achieved. The total production of ~2.5 tons was sold to local smallholder distributors and to people from the community. Some test sales were done to shops in the nearest city. Table 10 shows the achieved KPI's during the two growth cycles.

Table 10: Production of Tanganyika tilapia during the REPIC project duration using both commercial fish feed (from Zambia and Vietnam) and local farm-made feeds that were made with the TTA solar PV feed mill

Harvested Tanganyika tilapia during REPIC project (2 production cycles) [kg]	2'563
Average fingerling weight at stocking (ABW) [g]	3
% large fish at harvest (>100g)	76%
Harvest ABW large fish [g]	243
Total amount of feed fed [kg]	3'624
eFCR [kg feed/kg fish]	1.41
Growth period [days]	257
Local max. sales price per kg [TZS]	5000
Local max. sales price per kg [USD]	2.2
Local min. sales price per kg [TZS]	3000
Local min. sales price per kg [USD]	1.3
Regional sales price per kg [TZS]	9000
Regional sales price per kg [USD]	3.8

The first grow out cycle was done with commercial feeds only. In the second grow out cycle farm made feeds and commercial feeds were mixed.
Fish feed formulas for the farm-made feeds were developed by TAFIRI & SUSTAIN to include local ingredients (especially rice bran) and meet the needs of the Tanganyika tilapia (Table 11). Prior to the formulation, various ingredients had been analysed in the laboratory to determine most cost-efficient formulas. The ingredients used to make the feeds were locally sourced and included unused agricultural by-products like rice bran. The farm made feeds were made with the solar PV feed mill.

Table 11: Formula of locally made feed using the solar feed mill. Showing crude protein (CP), ether extract = lipids (EE), crude fibre (CF) and ash content of each ingredient and the total feed per kg. Cost column shows the cost contribution of each ingredient and the total cost per kg of feed produced.

Ingredient	Source	Formula	CP	EE	CF	Ash	Cost [USD]
Soya (full fat)	Smallholder farmer aggregation	40%	36%	18%	5%	6%	0.35
Groundnut	Smallholder farmer aggregation	13%	32%	40%	4%	6%	0.11
Sunflower seed cake	Smallholder processing facility	15%	27%	12%	24%	21%	0.02
Minerals & premix	Veterinary supplier	1%	0%	0%	0%	0%	0.03
Rice bran	Smallholder processing facility	21%	9%	9%	21%	22%	0.01
Maize flour	Smallholder processing facility	10%	7%	3%	2%	4%	0.02
Total (per kg feed)		100%	25%	16%	11%	11%	0.54

Achieved sales prices of the fish (wet weight) were at the low end of prior expectations with only 3’000TZS/kg (1.3 USD/kg) for small fish (<100g) and 5’000TZS/kg (2.2 USD/kg) for bigger fish (>100g) when selling to local communities and distributors. However, test sales to shops in urban areas have shown the upside potential with prices (easily) reaching 9’000 TZS/kg (3.8 USD/kg) for table sized fish starting at 200-250g. This shows that the development of a cold chain will be key for the scale up of TTA. Therefore, we already invested into the development of a solar powered ice machine using the solar-direct-drive system that is also used for the feed mill.

4.2.2.4 Smallholder aquaculture production

At project start, the goal was initially to support the establishment of up to 6 new smallholder fish ponds in Kipili region (incl. subsidizing of smallholder pond construction) as there were no smallholder fish farmers in the area yet. However, as outlined in chapter 4.1.1 this goal was adjusted to focus support on smallholder fish farmers that started on their own during the REPIC project duration. This will ensure organic growth of the sector without dependencies on subsidies.
So far, two smallholder fish farmers have been supported and a total of approximately 20’000 fingerlings have been supplied. Data collection from these two farmers was a challenge, as both did not keep any records despite initial training. This also made it hard to evaluate the feasibility of smallholder fish farming in the region (c.f. 4.2.1). However, both farmers emphasized that the growth rate of the fish as well as the market were the biggest challenges for them. Growth rates were supposedly much slower in the smallholder ponds than in the TTA ponds which shows the need for better and more aligned training and coaching for prospective farmers. The market locally is also a challenge for TTA and not only the smallholder farmers as outlined in 4.2.1, this will be addressed in the future scale up of TTA through the establishment of the ice-based cold chain which will also be used to distribute fish produced by the smallholder fish farmers to higher priced urban areas.

4.3 Multiplication / Replication Preparation

4.3.1.1 The Tanganyika Aquahub scale up

The main objectives of the TTA REPIC project was to assess the economic and technical feasibility of TTA. The decisions if a scale up should be pursued after the REPIC project's completion was thereby tied to pre-defined milestones that should be reached to decide how to continue (Table 12).

Table 12: Proof of concept milestones for go/no-go decision for the TTA scale up

Milestone to decide for scale up	Milestone achieved	Explanations
Working pilot facility	Milestone achieved	Well working off-grid pilot facility with committed team
Feed costs at 0.55-0.75 USD/kg fish produced (~0.55-0.	Milestone not achieved	Fish feed prices (& ingredients) have risen sharply since the final REPIC project proposal (fish feed +30-50%; ingredients 20-80%) The benchmark has been assessed in the two grow out cycle with commercial and farm made feeds. feeds: costs per USD/kg fish produced accounted to 1.8 USD/kg, with total production costs reaching an estimated 2.4 USD/kg at minimum and roughly 5 USD/kg at maximum (but mismanaged)
Fish sales price per kg at 5'000-6'000 TZS with annual demand likely above TTA production	Milestone achieved	Sales price of fish from first grow out cycle at 5'000 TZS/kg to local distributors for harvest sized fish. Test sales to shops in urban centers reached 9'000 TZS/kg. However, to reach this market, a cold-chain needs to be setup which will require larger volume of fish and Vast upside potential if regional distributors can be supplied (larger volumes & ice necessary).
Fingerling production costs <5 cents per piece	Milestone achieved	With the achieved fecundity in the REPIC project a production cost of ~1-2 cents per fingerling can be achieved
Estimated net-margin of >20% for the scaled-up TTA operation	Milestone partly achieved	The updated financial cost-benefit model (with KPIs assessed through the REPIC project) shows a potential net-margin of 15-20%.
Smallholder fish farming is feasible	NA	Very sparse data was available from the supported farmers to the point where an estimation of their production costs was almost impossible. However, with wholesale Tanganyika tilapia prices to shops in regional urban areas reaching 3.0-3.8 USD/kg, smallholder fish farming is highly likely to be feasible.

With the results from the REPIC project, SUSTAIN and Lake Shore Lodge are confident to continue with TTA as a joint venture and reach a first scale up stage in 2024. The plan for the scale up has been adjusted to reach the production target amounts outlined in Table 15 in chapter 5.1.1.1. Until end of 2023, TTA will be registered as a joint venture between SUSTAIN and Lake Shore Lodge. The implementation of the scale up stage will then commence in 2024. To reach the envisioned capacities, an investment of 170k to 240k USD is currently being raised from a mixture of public and private sources. The expansion/business plan/financial model for the scale up of TTA has been a working document since the inception of the project and includes a business plan (PowerPoint) and a financial plan (Excel).

4.3.1.2 SUSTAIN Switzerland

SUSTAIN is the lead institution of the REPIC TTA project. The company is a venture builder in the field of sustainable aquaculture. The company invests time and money in companies & startups that are involved in the development of a sustainable aquaculture value chain in East and Central Africa. Currently, SUSTAIN has an engagement/investment portfolio of 5 companies/startups (including TTA). The findings of TTA helped SUSTAIN to evaluate further potential engagement/investments and refine its strategy. The TTA REPIC project showed the technical and economic feasibility of a solar PV powered fish farming facility in East Africa. Through these learnings, SUSTAIN has updated its investment criteria/goals in regards to renewable energies and other topics (Table 13).

Table 13: SUSTAIN Switzerland investment criteria & goals

Criteria	Goals
Renewable energies	Electricity used by each operating company should come at least 80% from renewable energy sources
Resource efficiency	• Reach a fish-in-fish-out (FIFO) ratio of 1:20 (0.05) across the portfolio of companies. FIFO represents the kg of wild fish it takes to produce 1kg of farmed fish • Foster in-country fish feed production using local ingredients
Ecological sustainability	• Promote native species aquaculture (no engagement in invasive species) • No negative impact on biodiversity and ecosystems • Climate positive portfolio of companies
Gender & youth	• Reach at least 50% women employment in each company • Foster employment programs for youth (18-35)
Fair employment	• Foster local livelihood improvement, fair & above pay of employees • Each employee has healthcare, pension & worker compensation • Good working conditions and work safety for all employees

Further, SUSTAIN has focused on the establishment of an investment database to be able to finance the multiplication & replication projects mentioned in this chapter. An extensive lead list of potential investors (>300 contacts) mostly from the impact investment space has been set up and the team has done dozens of introduction calls, personal meetings and attended networking events to foster relationships and explore potential investment opportunities.
During the REPIC project, SUSTAIN has raised an additional >400k USD in commitments for its portfolio companies (incl. TTA) through the established investor database.

4.3.1.3 Tanganyika Blue

The learnings from TTA have already benefitted in a further fish farming project. In 2022, SUSTAIN and partners started a new aquaculture project in the northern part of Lake Tanganyika, near Kigoma. The project is called Tanganyika Blue (registered as Tanlake Samaki Limited) and the aim is to establish the first commercial cage aquaculture facility at Lake Tanganyika in Tanzania.
In 2023, Tanganyika Blue aims to produce 30 tons of Tanganyika tilapia. Like TTA, the facility will also be solar powered (most probably a central, grid-tied system) to power the water supply system of the farm, the ice machine and hatchery and thereby use and expand on the AQUASMART Concept.

4.1 Impact / Sustainability

The TTA REPIC project has already created measurable ecological, economic and social impact (Table 14). Through the REPIC project investments it was possible to prevent the use of thousands of litres of diesel to power the TTA offgrid fish farming facility. Further, the production of fingerlings at the TTA facility helped to offset emissions from transportation from Zambia which was previously necessary to obtain fingerlings. The project did not reach its target goals on upcycling of previously unused agricultural by-products because of the delay in setting up the solar powered feed mill. However, in the coming year, this goal should be reached.
Economically, the project was able to create local private income through its business activities and initial setup (e.g. local labour for facility establishment etc.). Further, over 350k CHF of scale up and multiplication investments were secured during the project.
The number of beneficiaries as well as number of new jobs created was slightly lower than initially planned due to the decision to scale down the initial facility due to price hikes on major project costs (inputs, capital investments etc.). The number of trained personnel was much higher than expected through a joint 4-week training program for fish farmers and aquaculture lecturers that was organized by TTA, Bongo Samaki, SUSTAIN, Q-Point and the Tanzanian Fisheries Education and Training Agency (FETA).

Table 14: Overview of measured impact metrics planned vs. achieved of the TTA REPIC project (detailed evaluation can be found in chapter '8.3 Evaluation of impact metrics (Table 14)')

		At the REPIC Project's Completion	
Ecological	**Unit**	**Planned**	**Achieved**
Installed renewable energy capacity	[kW]	12.46	13.63
Renewable energy produced	[kWh]/year	20'873	15'793
Amount of fossil fuel energy saved	[kWh]/year	141'820	91'248
Greenhouse gas reduction	[t CO_2-eq]/year	45.037	28.726
Newly recycled waste	[t]	30	2.5
Economic			
Energy costs (LCOE)	[ct/kWh]	11	12
Triggered third-party funding/investments	[CHF]	250'000	>350'000
Local private income generated	[CHF]	24'000	>30'000
Social			
Number of beneficiaries	[Number]	550	250
Number of new jobs	[Number]	11	6
Number of trained personnel	[Number]	25	60

5. Outlook / Further Actions

5.1 Multiplication / Replication

5.1.1.1 SUSTAIN Switzerland

SUSTAIN's goal is to build a portfolio of aquaculture value chain companies in East Africa with assets over 2m USD by end of 2023 and scale to >8m USD by 2027. In 2023 and 2024, the focus will mostly be on the ventures in the West of Tanzania at Lake Tanganyika (The Tanganyika Aquahub TTA, Tanganyika Blue, c.f. chapters 5.1.1.2 and 5.1.1.3).

5.1.1.2 The Tanganyika Aquahub scale up

Until end of 2023, TTA will be registered as a joint venture between SUSTAIN and Lake Shore Lodge. The implementation of the scale up stage will then commence in 2024. To reach the envisioned capacities, an investment of 170k to 240k USD is currently being raised from a mixture of public and private sources.

Table 15: TTA scale up stage I (2024-2025) production targets

Description	Initial annual targets	Adjusted annual targets	Explanations
Tanganyika tilapia fingerlings	2 million fingerlings	2-4 million fingerlings	Fecundity (eggs per female) of the Tanganyika tilapia is higher than what was expected and therefore the hatchery capacity will be higher than anticipated
Table sized Tanganyika tilapia	50 tons	20-30 tons	Scale up stage I will now be done on the existing plot (not outside Lake Shore's premises as previously planned), an estimated production of 20-30 tons can be reached on the plot
Farm made feeds	300 tons	50 tons	Lower target production of fish, lower feed needs and productivity of the SSD solar feed mill lower than expected
Ice	0	40 tons	REPIC project has shown the importance to produce ice on the farm. This will also benefit the outgrower program. The ice will be used to setup an ice-based cold chain to supply shops in urban centers
Training center	Training of 10-20 people per year	Training of 50-100 people per year	During the REPIC project we identified the lack of awareness and training to be one of the major constraints for sustainable aquaculture development in the region and decided to focus further on that in the future

5.1.1.3 Tanganyika Blue & AQUASMART scale up

The goal of Tanganyika Blue is to expand its production capacity to 500 tons p.a. by 2024 and then scale up to 3’000 tons p.a. by 2027. The project will ensure direct employment for >200 people and sustainable supply of fish to close to half a million people.
Until end of 2023, TB will complete its financing, finalize regulatory processes and establish its holding & trading company in Switzerland. Further, the company will produce 20-30 tons of Tanganyika tilapia in its pilot facility in Kigoma and start establishment of the 500 ton farm on the acquired 25ha of land 30km from Kigoma. In June to September 2023, SUSTAIN and ZHAW will work together on the development of the energy concept of the future TB facility. The TB energy concept will be an adaptation from the TTA energy concept and also incorporate AQUASMART. The goal is then to expand AQUASMART to a fully integrated data management solution for fish farms like TTA & TB.
Major current hurdle is the completion of the financing. As mentioned in chapter 4.3.1.2 SUSTAIN has started engagement with numerous potential investors, however, it has been a challenge to get mission-aligned equity investors on board for a greenfield project like Tanganyika Blue. Total investment needs for the first scale up stage to 500 tons p.a. account to 1.5m USD, whereof 300k USD have already been committed by a mixture of public & private investors.

5.1.1.4 MOOC in sustainable tropical aquaculture ZHAW & SUSTAIN

Together with ZHAW, SUSTAIN develops a massive open online course (MOOC). The course will build on videos taken at TTA and use TTA as a case study including the use of solar PV. The goal is to set up the MOOC during 2023 and start the first cohort in early 2024.

5.2 Impact / Sustainability

The planned and already started multiplication and replication projects mentioned in chapter 5.1 will have substantial sustainability impact over the next 3 years. Table 16 shows the potential annual impact of the multiplication/replication projects on ecological, economic and social levels by the year 2025. This assumes that the Tanganyika Blue solar powered fish farming facility will be scaled to a production capacity of 500 tons p.a., The Tanganyika Aquahub reaching the envisioned numbers mentioned in Table 15 and the sustainable tropical aquaculture MOOC being rolled out successfully and repeated frequently (similar to the previously developed aquaponics MOOC by ZHAW that has seen over 7’000 enrolments since its start in 2021).

Table 16: Estimated potential annual impact of the replication & multiplication projects by 2025

Ecological	**Unit**	**Target 2025 across SUSTAIN portfolio (p.a.)**
Installed renewable energy capacity	[kW]	100-200
Renewable energy produced	[kWh]/year	150’000-300’000
Amount of fossil fuel energy saved	[kWh]/year	750’000
Greenhouse gas reduction	[t CO_2-eq]/year	300
Newly recycled waste	[t]	30
Economic		
Energy costs (LCOE)	[ct/kWh]	11-13
Triggered third-party funding/investments	[CHF]	2'000’000
Local private income generated	[CHF]	100’000-400’000
Social		
Number of beneficiaries	[Number]	100’000
Number of new jobs	[Number]	100
Number of trained personnel	[Number]	1’500

6. Lessons Learned / Conclusions

Technical learnings:

- ~100% SDD (solar-direct-drive) powered fish farming hatchery is feasible.
- SDD water supply is feasible. A good backup is key for long periods of low irradiation.
- SDD feed mill is technically feasible, but expensive to set up (savings on batteries were offset by more expensive 'specialized' equipment & high engineering effort).
- To increase energy efficiency for a facility like TTA, a central solar system would theoretically be more feasible. This way the 'overproduction' for one appliance (e.g. water supply system) can be used for other appliances (e.g. ice machine). However, in practice this is not always possible due to incompatibility of certain turnkey solutions (e.g. in our case the solar feed mill and water supply system were not compatible) and can also come with increased establishment costs (e.g. long DC cables) that can offset the energy efficiency and make separate systems more feasible.
- The solar contractor is key for the above setups. Figure out if they are capable of carrying out such a project by checking on references and having 'engineering-like' discussions with them.
- Looking at online weather forecasts can help the management of a solar powered operation like TTA. In our case the data was precise but not accurate (we saw consistent errors from the online model compared to our own weather station on the ground).
- A predictive model (like AQUASMART) can help even more. As long as the online weather models are precise they can also be inaccurate and the consistent errors can be adjusted by a suitable machine learning model. However, the development of such a model demands high data engineering effort and extensive know-how in data analytics.

Management learnings:

- The initial signed MoU between the project partners helped to coordinate the project and bring transparency for deliverables and workflows
- Project management through Microsoft Teams and WhatsApp groups was more efficient than regular calls, mostly due to unreliable internet connection in Tanzania
- 'Independent' work packages can help to be adaptable to delays caused by unforeseeable circumstances (force majeure)

7. References

ZHAW & SUSTAIN IWMI Presentation on "Application of solar technologies in aquaculture in Cambodia an Tanzania – technology transfer and training", 07/02/2023

BBC Swahili Report on Tanganyika Blue (Tanganyika Blue is legally registered and therefore referred to in the BBC Swahili report as Tanlake Samaki Limited)

Example Training report AquaBoost Songea 2022 (in total 4 trainings like this were organized in collaboration with the TTA team, Bongo Samaki, SUSTAIN, Q-Point and FETA)

8. Annex

8.1 Pictures & Videos

Disclaimer: The pictures included in this annex are the property of SUSTAIN Switzerland, ZHAW, Lake Shore Lodge, Bongo Samaki and TAFIRI (hereinafter referred to as 'SUSTAIN & CO'). These pictures are provided solely for the purpose of illustrating the project outcomes. Any use/reproduction of these pictures for any other purpose requires prior written consent from SUSTAIN & CO.

- Introduction Video TTA
- Videos & Pictures of TTA
- Pictures of co-organized trainings

8.2 LOI Ethical Seafood Research and SUSTAIN Switzerland

Ethical Seafood Research (ESR) is a UK based company that has committed to co-invest in the multiplication project Tanganyika Blue.

ESR Ethical Seafood Research

SUSTAIN Towards a Sustainable Blue Revolution

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Glasgow, Scotland
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To whom it may concern 08/06/2023

Letter of Intent: Collaboration and co-investment into the development of sustainable, ethical and humane aquaculture value chains in in East Africa

This is to confirm the mutual interest of Ethical Seafood Research (ESR) and SUSTAIN Switzerland to collaborate and co-invest into the development of sustainable, ethical and humane aquaculture value chains in East Africa and especially in the Lake Tanganyika Region.

The collaboration and co-investment is especially focused on the following aspects:

- Development of Tanganyika Blue, the first commercial cage aquaculture farm on Lake Tanganyika in Tanzania. The venture is located near Kigoma where it currently operates a pilot facility in collaboration with TAFIRI. The company aims to scale up to an annual production capacity of 500 tons of Tanganyika tilapia by 2024.
- Scale up of The Tanganyika Aquahub (TTA) in Kipili, Tanzania. TTA is the first Tanganyika tilapia hatchery in Tanzania and operates a fully solar powered input production facility including a hatchery and a small scale feed mill. Over the next 2 years, the goal is to scale up the annual production capacity of the facility to 4 million Tanganyika tilapia fingerlings, 50 tons of fish feed, 40 tons of ice and 20 tons of table-sized Tanganyika tilapia. Moreover, a training centre will be established to provide hands-on training for up to 100 people per year on sustainable, humane and ethical aquaculture.
- Implementation of sustainability concepts in the above mentioned ventures including fostering the use of renewable energies and the use of locally available resources to increase resource efficiency.
- Collaboration on fish welfare with the goal that Tanganyika Blue and The Tanganyika Aquahub become pioneers and flagship projects to showcase high welfare practices in fish farming operations
- Building of networks and strong partnerships with key stakeholders to achieve the above.

This letter of intent is signed with the best intentions by the representatives of the two parties.

Wasseem Emam	Severin Spring
Founder	Co-Founder
Ethical Seafood Research	SUSTAIN Switzerland GmbH

8.3 *Evaluation of impact metrics (Table 14)*

Calculations are based on methods used in the REPIC proposal.

Installed renewable energy capacity:
According to manufacturer specifications

Renewable energy produced:
Used data from the solar water supply system which measured the power usage of the pump in 10min intervals each day for 11 months. This accounted to 7’665 kWh. We then used this value to estimate the yearly PV production of the solar feed mill and solar hatchery which then accounts to 7’665 kWh / 6615 kWp x [6675 + 340] kWp = 8’128 kWh. The total renewable energy produced can then be estimated to reach 7’665 kWh + 8’128 kWh = 15’793 kWh.

Amount of fossil fuel energy saved:
Fossil energy saved through the use of solar PV
Assumptions
Energy density of diesel of 9.79kWh/l
Generator fuel consumption: 0.5l diesel per kWh electricity production
Water supply system
Energy (electricity) requirement of system: 21.5 kWh per day, 7’665 kWh per year
Fossil energy saved from solar water supply: [yearly energy requirement of system] x [generator fuel consumption] x [energy per litre of diesel] = 7’665 kWh/a x 0.5l/kWh x 9.79 kWh/l = 37’520 kWh
Feed mill
Energy (electricity) requirement of system: 21.2 kWh per day, 7’734 kWh per year
Fossil energy saved from solar feed mill: [yearly energy requirement of system] x [generator fuel consumption] x [energy per litre of diesel] = 7’734 kWh/a x 0.5l/kWh x 9.79 kWh/l = 37’858 kWh
Hatchery
Energy (electricity) requirement of system: 0.4 kWh per day, 144 kWh per year
Fossil energy saved from solar hatchery: [yearly energy requirement of system] x [generator fuel consumption] x [energy per litre of diesel] = 144 kWh/a x 0.5l/kWh x 9.79 kWh/l = 705 kWh
Total fuel energy saved through the use of solar PV:
37’520 kWh + 37’858 kWh + 705 kWh = 76‘083 kWh
Fossil energy saved through decrease of transportation emissions (import of inputs from Zambia)
Assumptions
Energy density of diesel of 9.79kWh/l
Amount of feed to transport to Kipili from Lusaka: 10 tons
Feed transportation distance Lusaka-Kipili: 2’572km (roundtrip)
Specific fuel consumption feed transportation (10 ton vehicle): 40l/100km (internal data)
Feed transportation emission factor: 140g/tkm (EAA, 2017)
Fingerling transportation distance Ndole-Kipili: 1’300km (roundtrip)
Fingerling trips per year: 4
Specific fuel consumption fingerling transportation (pickup): 10l/100km (internal data)
Feed
Fossil energy saved through feed transportation emission savings: [amount of feed transported]/10 x [distance per trip] x [specific fuel consumption] x [energy density of diesel] = 10t/10 x 2’572km x 40l/100km x 9.79kWh/l = 10’074 kWh
Fingerlings
Fuel energy saved from producing fingerlings locally: [number of trips per year] x [distance] x [specific fuel consumption] x [energy density of diesel] = 4 x 1’300km x 10l/100km x 9.79kWh/l = 5’091 kWh
Total fossil energy saved
[fossil energy saved from solar water supply] + [fossil energy saved from solar feed mill] + [fossil energy saved from solar hatchery] + [fossil energy saved through feed transportation emission savings] + [fossil energy saved through fingerling transportation emission savings] = 37’520 kWh + 37’858 kWh + 705 kWh + 10’074 kWh + 5’091 kWh = 91’248 kWh

Greenhouse gas reduction
CO_2e emission of 3.082 kg CO_2e /l diesel

Energy density of diesel of 9.79kWh/l
Greenhouse gas reduction: [Total fossil energy saved] / [energy density of diesel] * [CO2e emission of 1l diesel] = 91’248 kWh / 9.79 kWh/l * 3.082kg CO2e/l diesel = 28’726 kg CO2e

Newly recycled waste
The amount of agricultural by-products that are used for local fish feed manufacturing (which would otherwise be discarded): 2’500kg of rice bran

Energy costs (LCOE)
The energy cost calculations were done with a cost-benefit analysis across all solar installations (incl. additional costs such as exchange of feed mill machines)

Description	Total [USD]	Depreciation per year [USD]
Solar installation cost	26’155	1’308
Extra equipment (e.g. adjusted engines)	5’249	750
Total solar PV related CAPEX	31’404	2’058
Solar PV production [kWh/year]		15’793
LCOE [USD/kWh]		0.13
LCOE [CHF/kWh]		0.12

Triggered third-party funding/investment
Total further acquired financing for TTA and replication/multiplication projects.

Local private income generated
The private income generated was estimated from the amount spent during the REPIC project on services and materials from the community. Further included are estimated incomes from fish trading and farming.

Number of beneficiaries
Estimated total number of people that have directly or indirectly benefitted from the REPIC project.

Number of new jobs
The number of new jobs (full time equivalent) created through the TTA REPIC project.

Number of trained personnel
Number of people trained during the REPIC project. Including stakeholders trained at TTA directly and also people trained in co-organized trainings with SUSTAIN, FETA and Q-Point.