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VicInAqua

Integrated aquaculture based on sustainable water recirculating system for the Victoria Lake Basin

Deliverable 6.2
LCA Benchmark report for sanitation and aquaculture

Revision: **1.0**
Due date: **30/11/2018 (M30)**
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PU	Public	PU
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DoA	Description of the deliverable as reflected in the DoW (it can be edited, if necessary) This focuses on the assessment of environmental and sustainable impact of the VicInAqua integrated sanitation and RAS compared to conventional aquaculture and sanitation methods used in the Lake Victoria Basin.				
Comments					

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Contents

1.0 ABSTRACT

There is a high demand for fingerlings around the Lake Victoria due to the preference of fish as the main source of protein among the population in the region. The supply of fish from the lake has been dwindling with time due to overfishing and poor quality of the lake water as a result of discharge of waste water into the lake. RAS offers a sustainable supply of fingerlings where the limited water available is recycled. The VicInAqua pilot offers a solution in the sense that the polluted water is cleaned through an MBR system and the RAS is run with renewable energy. For the VicInAqua solution to be acceptable, it must deliver low environmental impacts. The Chain Management by Life Cycle Assessment (CMLCA) software was used with the ecoinvent database providing the Life Cycle Inventory. The RAS was assumed to have a lifetime of 20 years. GHG emissions were found to be mainly contributed by the fish feed which is manufactured mainly from rice, maize and soybeans. Human toxicity potential is expected mainly from fibreglass production while ecotoxicity potential is mainly from the arsenic in glass fibre production.

2.0 DEVIATION FROM THE WORKPLAN

The Presentation of deliverable D6.2 was delayed after the PhD student who was tasked with handling the LCA (Mr Joseph Mbothu) left to France in October 2018 for a few months of study. The data collected for the deliverable was given to Ms Purity and Dr Njogu for analysis. However, the duo were not familiar with the softwares used in LCA and could therefore not generate the Life Cycle Impacts (LCI) results. Mr Mbothu came back this February and continued from where he had left. He completed the computer analysis of the LCI results which were necessary for the compilation of the report.

3.0 INTRODUCTION

Recirculating aquaculture systems (RAS) are self-contained growing environments mainly for producing fish. RAS allow fish to be grown at high density under controlled conditions. This maximizes fish growth all year-round and gives the flexibility to locate the production facilities near markets and allow complete and convenient harvesting. RAS can be used to maximize production where suitable land or water is limited, or where environmental conditions are not ideal for the fish species being reared. The fish are reared in tanks, and water is exchanged continuously to guarantee optimum growing conditions. The water is pumped into tanks, through mechanical and biological filters and then back into the tanks. Small amount of water is added either daily or weekly. RAS components, functionality and production capabilities can all vary greatly, but must have sub-units for solid removal, biological filtration, water flow and the culture for fish to live in. Therefore, different designs of RAS should accomplish aeration, removal of particulate matter, biological filtration to remove waste ammonia and nitrite and buffering of pH. This study aims to determine the environmental impacts of the VicInAqua RAS for Victoria Lake Basin from a life cycle perspective. LCA has been used previously to assess the sustainability of aquaculture systems (McGrath *et al.*, 2015; Henricksson et al, 2016, Yacount *et al*., 2016). It is a powerful tool to assess environmental sustainability as it provides a comprehensive quantification of direct and indirect environmental impacts (Forchino *et al.*, 2017).

Aquaculture (farming fish under controlled conditions) in Kenya is a new technology aiming to satisfy a growing market for fish and also alleviate poverty in rural areas. Wild fish populations have declined due to overharvesting and water pollution. This has promoted farmed fish that are grown in static ponds, tanks and cage systems. Instead of the traditional method of rearing fish outdoors in open ponds and raceways, RAS rears fish at high densities in tanks and raceways in a "controlled" environment. Aquaculture since the 1970's has been a very fast-growing industry and it is anticipated to grow to 41% by 2020 (Carlos *et al.*, 2015). Fresh water fishes dominate global aquaculture production (FAO, 2012). Nile tilapia (Oreochromis niloticus) is the most consumed ad cultured fish species worldwide (Sarpong *et al.*, 2005). The Nile tilapia (Oreochromis niloticus) fingerling production is important for continual expansion of the global tilapia aquaculture (Lutterodt,J.B., 2018). In production of fingerlings, good management practice at the breeding stage is very critical so as to increase the hatching success (Lutterodt,J.B., 2018).

Aquaculture in developing countries improves food security and supplements income for rural families. In many countries in Africa, aquaculture is done at subsistence level and the surplus production is sold in rural markets (Subasinghe *et al.*, 2012). The emphasis of Kenya government aquaculture policy initiatives has been on social objectives such as improved nutrition in rural areas, generation of income, diversification and creation of employment (Kwamena *et al.*, 2010). Kenya's aquaculture is a small industry practised to produce Nile tilapia and African catfish (FAO, 2010). In 2010, Nile tilapia contributed 75% of the total farmed fish produced (FAO, 2010). There has been a rapid growth of aquaculture in many parts of Kenya and this has necessitated a high demand of quality fingerlings for the commonly cultured species, Nile tilapia and African catfish (KMFRI, 2017). The availability of quality fingerlings is a major prerequisite for sustainable aquaculture. In 2009, there were only 21 hatcheries producing either Nile tilapia or African catfish fingerlings, but in June 2012 the number increased to 147 in various parts of the country but dropped to 127 by 2015 producing 96 million fingerlings (KMFRI, 2017). The figure below depicts the change in number of hatcheries between 2009 and 2015.

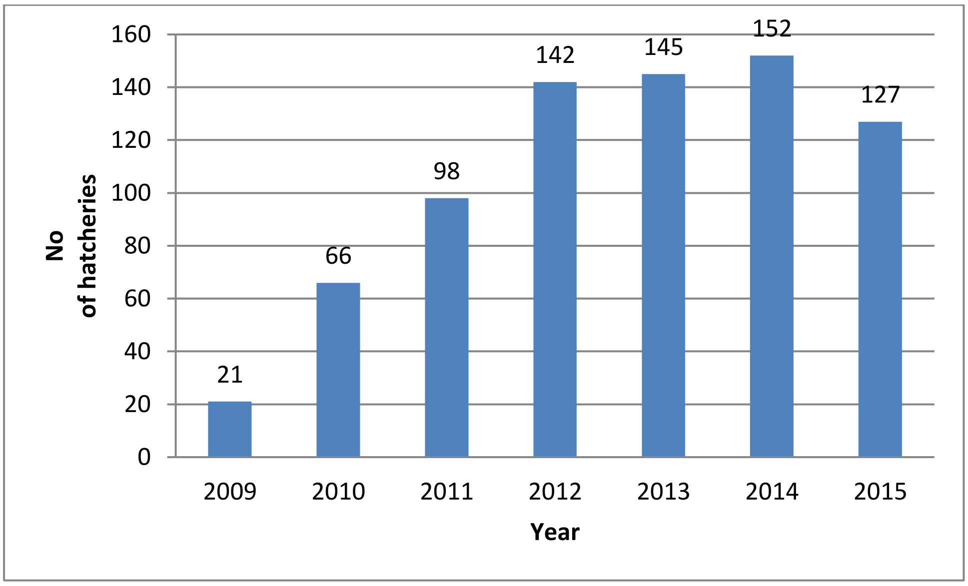

Figure 1: Change in number of hatcheries (2009-2015)

4.0 THE VICINAQUA PILOT PROJECT IN KISUMU, KENYA

The VicInAqua project developed self-cleaning water filtration solutions adapted for sanitation of different wastewater systems to be reused in Recirculating aquaculture systems (RAS). The main goal of the project is to supply clean water to RAS and agriculture through a single solution for wastewater treatment of different waste water streams. The power supply is mainly intended from renewable energy (Photovoltaic, biogas, thermo-electric generation) and remotely monitored with sensor technologies. In the VicInAqua system, a tilapia hatchery is designed for fish cultivation and therefore high-quality water use is essential. The tilapia hatchery uses RAS technology so as to conserve water and reduce waste discharges. The hatchery is intended to produce high quality fingerlings to supply pond aquaculture in the area.

The components of the VicInAqua system include; Membrane bioreactor (MBR), Recirculation aquaculture systems (RAS), Monitoring and control system and the Energy supply systems. The membrane bioreactor system combines the biological wastewater treatment and membrane filtration. It consists of a mechanical pre-treatment, denitrification tank, aeration tank, and a filtration tank. The filtrate from MBR is stored in a 2000l tank and is sterilised by UV before being distributed to RAS or agriculture. The RAS consists of three major units; Broodstock and egg incubation (6 tanks), Larva rearing (9 tanks), Nursery (12tanks) shown in Appendix I. These units have electricity consuming subunits whose energy consumption is dependent on power consumption of the subunit, percentage power at working point and duty time per 24 hours as depicted in Appendix II.

5.0 LIFE CYCLE ASSESSMENT (LCA) METHODOLOGY

LCA is composed of four steps: (1) Goal and scope definition (2) Life Cycle Inventory –LCI (3) Life Cycle Impact Assessment - LCIA (4) Interpretation and analysis of results.

5.1 Goal, Scope Definition and Functional Unit

The study aims to estimate and quantify environmental impacts and identify the hotspots within the RAS in rearing of tilapia fingerlings. The fingerling's weight ready to be sold to pond owners should be 1-2 grams. The functional unit (FU) is defined as number of fingerlings produced in a period of one year.

5.2 System Boundary

The production of tilapia fingerlings in the RAS are modelled on a cradle-to-gate approach. The system boundary include all processes in the RAS production as depicted in Figure 1: The inputs include; energy consumption, RAS infrastructure and fish feed production while the outputs are the tilapia fingerlings.

5.3 Life Cycle Inventory (LCI)

The inventory materials and weights are for one year time boundary. Data for system inputs/outputs (energy and consumables) that is considered are thus for one year period. The study considered the following; extraction and production of raw materials for the infrastructure, and extraction and production of fish feed. Transportation, packaging and capital goods such as water pumps, control units, electronic equipment were not included in this study.

The equipment and materials considered in the study include polypropylene, polyethylene, polyvinylchloride (PVC), steel, concrete, and fibre glass. The quantity of these materials used was calculated and is shown in Table 1. The quantity of feed used per year, fingerlings produced per year is also depicted in Table 1. The energy consumption of the project is presently from the solar PV and the national grid. The energy conversion from solar PV is slow and not effective, hence using national grid for a long period of the time. On average 54% of the electricity was found to come from the grid, 46% from the solar PV. Presently, 87% of the Kenya's grid electricity generation mix is from renewables. In summary, 46% was from the solar PV, 40% from other renewables and 14% from non-renewables. Table 2 shows the summary of the energy consumption as calculated from the data in Appendix 1. The inventory for background processes was obtained from the Ecoinvent databases as depicted in Appendix III.

Table 1: Material input/output

Material	Quantity
Polypropylene	90 kg
Polyethylene	124.4 kg
Fibre glass	1209 kg
Polyvinylchloride (PVC)	102 kg
Steel	2388 kg
Concrete	152.7 m^3
Feed	1600 kg/year
Fingerlings	300,000/ year

Table 2: Equipment energy consumption

Type	Energy consumption (kWh/day)
Filter system	15.84
Broodstock	54.8
Larvae weaning	36.8
Nursery	35.84
Additional	37.56
Total	180.84

5.4 LCA Software, Database and Environmental Impact Methodology

Chain Management by Life Cycle Assessment (CMLCA) software is used for this LCA study. The software allows quantifying and communicating with indicators the environmental performance of products and processes. Processes for material extraction and production were obtained from the Ecoinvent databases. The CMLCA software is compatible with Ecoinvent database. Ecoinvent is a comprehensive life cycle inventory (LCI) database in such areas as energy supply, construction materials, wood, transport, biofuels etc. The life of the RAS was assumed to be 20 years. The modelling in CMLCA for materials used was one year and thus calculation for conversion factor for equipment materials:

$$\frac{1 \text{ equipment material}}{20 \text{ years}} = \frac{1}{20} \text{ equipment material/year}$$

The study used CML-IA methodology for environmental impact assessment. The CML-IA methodology, developed by CML (Centre of Environmental Science of Leiden University, Netherlands) restricts quantitative modelling to early stages in the cause-effect chain to limit uncertainties. It groups LCI results into midpoint categories according to themes; these themes are common mechanism (e.g. climate change) or groupings (e.g. human toxicity)

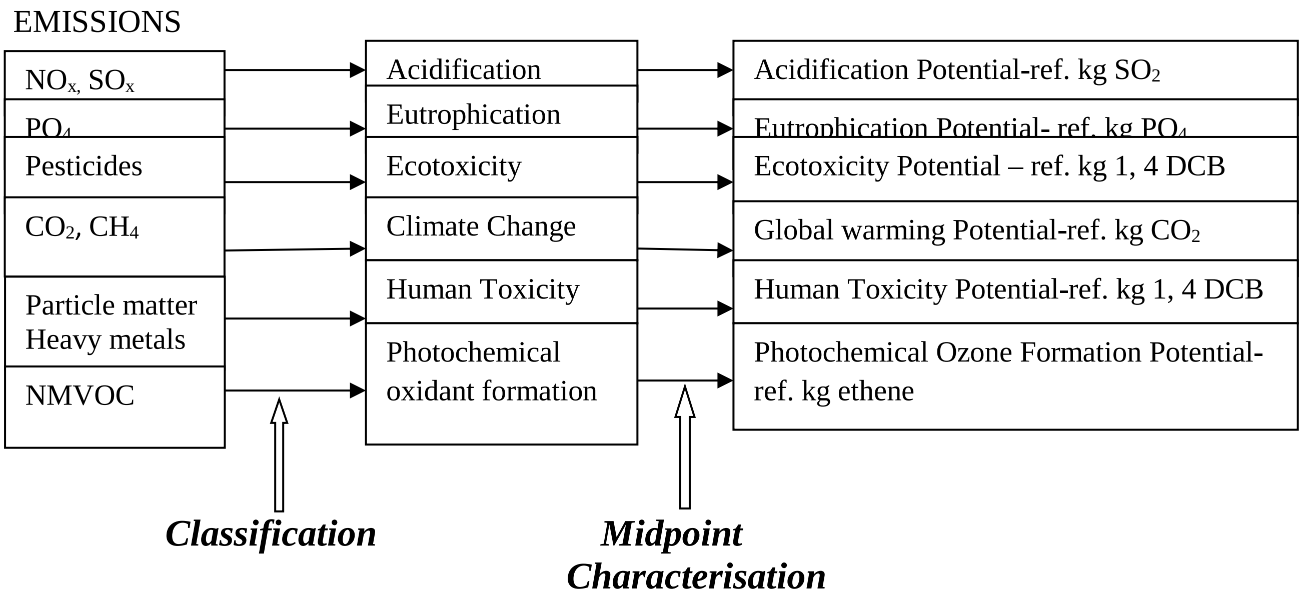

Figure 2: CML-IA methodology for classification and characterisation

NB: Beyond midpoint characterization there is normalization and weighting for each category.

Each impact category is characterized by midpoint indicator using a defined reference substance to quantify the impacts in relation to the reference substance. The study has determined the following classes of environmental impacts; Climate change, Acidification, Eutrophication, Human toxicity, Ecotoxicity and Photochemical oxidant formation.

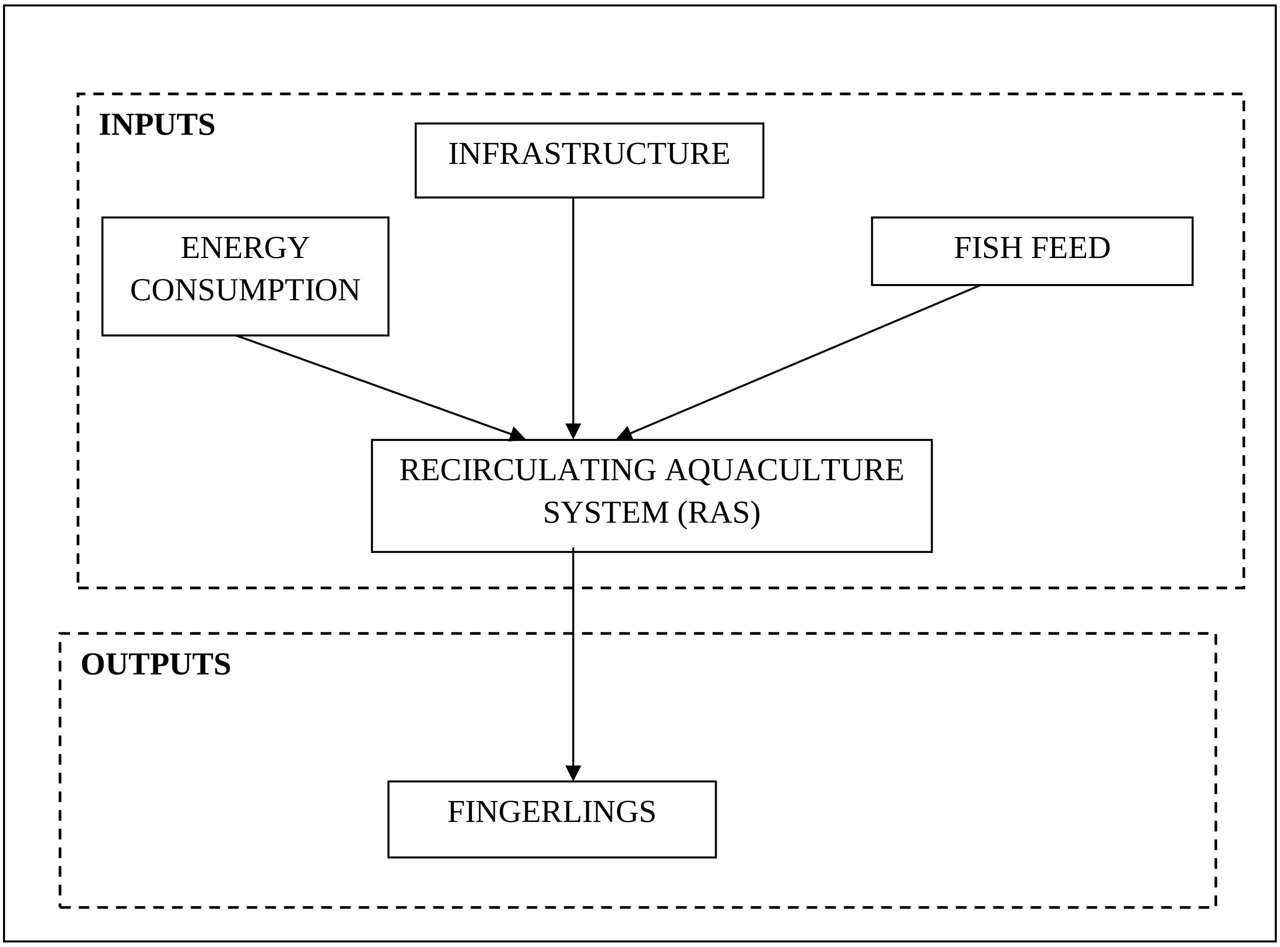

Figure 3: System boundary for RAS

6.0 LIFE CYCLE IMPACT ASSESSMENT (LCIA) RESULTS

Results show that in the production of 300,0000 fingerlings, the key emissions generated include 2.97E+04 kg of carbon dioxide[air], 333 kg of nitrogen oxides[air], 92.4 kg of carbon monoxide[air], 44.5 kg of particulates[air], 24 kg of methane[air], 9.3 kg of sulphur dioxide[air], 1.8 kg of nitrous oxide [air], 1.29 kg of ammonia[air], 48 kg of nitrate[water], 13.2 kg of BOD[water] and 7.25 kg of COD[water].

6.1 Global Warming/GHG Emissions

The estimated net GHG emissions are 30.8 t CO_{2eq} in the production of 300,000 fingerlings. .As depicted in Figure 4, CO_2 contributes about 96%, followed by N_2O (2%) and CH_4 (2%)

of total GHG emissions. Feed ingredients production (rice, maize and soybean) is the major sources of the GHG emissions, and this due to use of fossil diesel for land tillage.

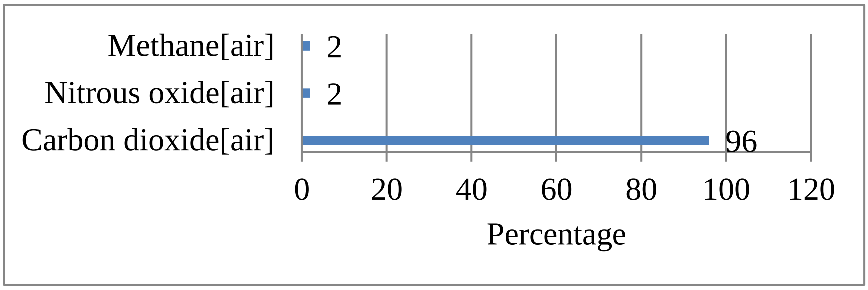

Figure 4: Emissions Causing Global Warming

6.2 Acidification Potential (AP)

The acidification potential (AP) in the production of 300,000 fingerlings is estimated to be about 245 kg SO_{2eq}. As depicted in Figure 5, NO_x is the major acidifying pollutant with a contribution of about 95%, followed by SO_2 (4%) and NH_3(1%) of total AP. NO_x and SO_2 emissions are mainly from use of diesel in land tillage for fish feed production. Small amounts of the later come from cement and fibre glass production.

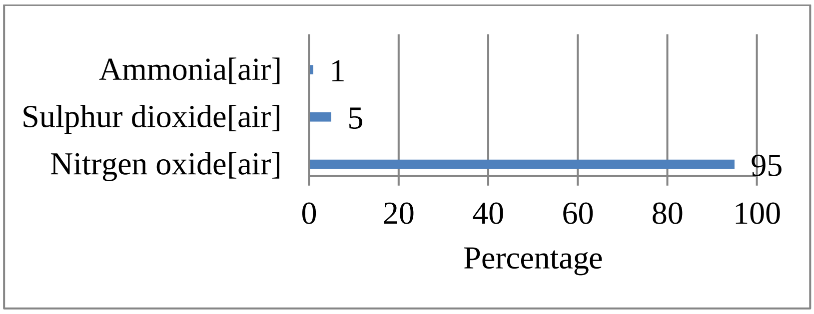

Figure 5: Emissions Causing Acidification

6.3 Eutrophication Potential

Eutrophication is due to nutrient enrichment in both aquatic and terrestrial ecosystems. The eutrophication potential (EP) in the production of 300,000 fingerlings was calculated at about 50.2 kg PO_4^{3-} . In this study, emissions of nitrogen oxides (NO_x), ammonia (NH_3), and nitrous oxide (N_2O) emitted to air, nitrate(NO_3^-) and Total-P emitted to water contribute to eutrophication impact. Figure 6 depicts the contribution of each of these emissions to the total EP i.e. Total-P (2%), NH_3 (1%), NO_x (86%), NO_3^-(10%) and N_2O (1%). The emissions are emitted during fish feed ingredients production.

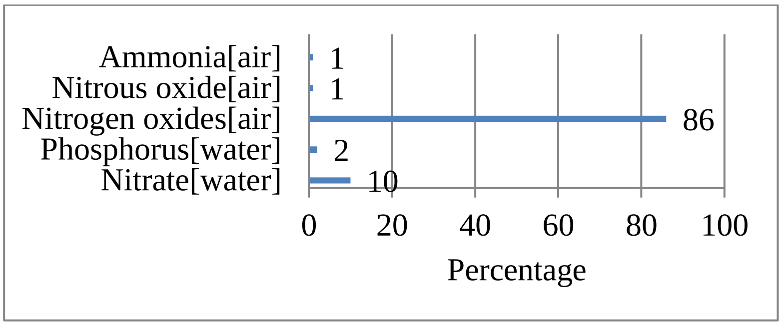

Figure 6: Emissions Causing Eutrophication

6.4 Human Toxicity Potential (HTP)

Human toxicity is due to a long time exposure to toxic substances or chemicals that have potential to cause negative human health effects. This study estimated the human toxicity potential (HTP) at about 783 kg 1, 4 DCB eq in the production of 300,000 fingerlings. HTP is due to emissions of heavy metals cadmium and copper, NO_x, HF and particulates into air. Figure 7 shows the contribution of each of these emissions to the total HTP. Cadmium and HF was mainly from glass fibre production, while copper, NO_x and particulates are from use of diesel in ploughing of land for fish feed ingredients production.

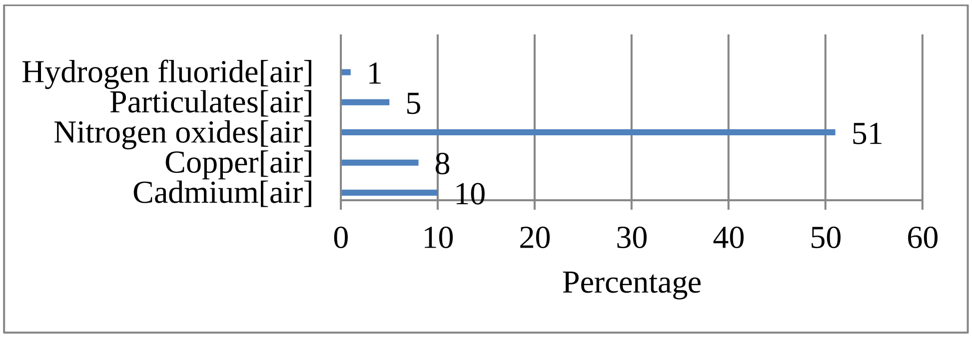

Figure 7: Emissions Causing Human Toxicity

6.5 Ecotoxicity Potential (ETP)

Ecotoxicity potential ((ETP) in the production of 300,000 fingerlings was estimated to be 21.6 kg 1, 4-DCB. As depicted in Figure 8, ecotoxicity was found to be due to emissions of heavy metals arsenic (As), chromium (Cr), copper (Cu), zinc (Zn) and lead (Pb). As is from fibre glass production (95%) and clinker production (5%), Pb emissions are from phosphate fertilizer production, and Cr, Cu and Zn are mainly from diesel use in land tillage. Few amounts of Cr are emitted from clinker band steel production.

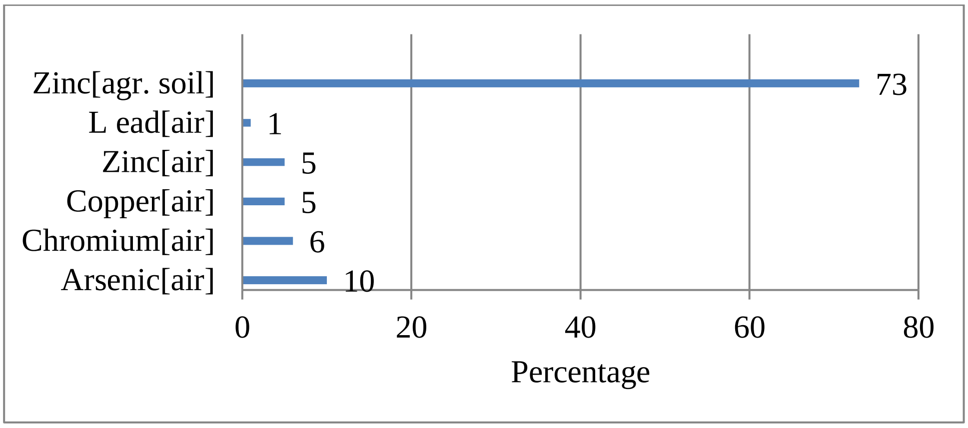

Figure 8: Emissions Causing Ecotoxicity

6.6 Photochemical Ozone Creation Potential (POCP)

The calculated photochemical ozone creation potential (POCP) in the production of 300,000 fingerlings was estimated at about 3.1 kg ethene eq. As shown in Figure 9, this impact is due to the following emissions; carbon monoxide (CO), sulphur dioxide (SO_2), methane (CH_4) which contributed 80, 14 and 6 % respectively to the total POCP. CO and SO_2 emissions are produced mainly from fish feed ingredients production due to use of diesel in land preparation. CH_4 emissions are mainly from rice production (95%) with little from diesel use (5%) in land tillage.

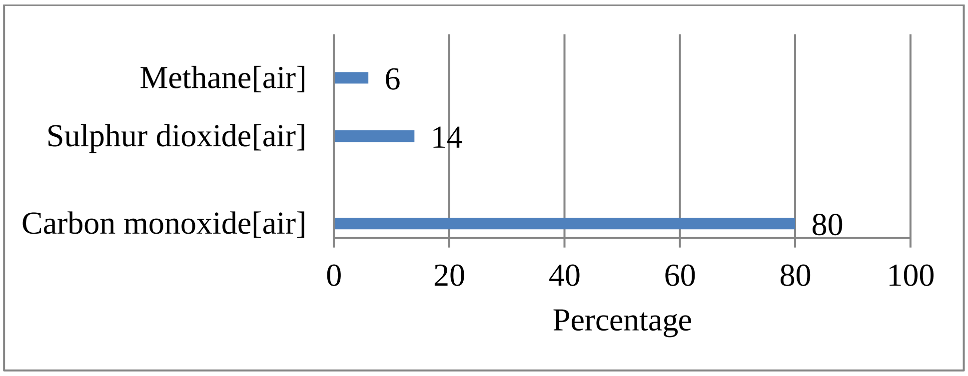

Figure 9: Emissions Causing Photochemical Ozone Formation

7.0 CONCLUSIONS

Assuming a lifetime of 20 years for VicInAqua pilot, it has been found that the main environmental impacts arising from the VicInAqua pilot are broadly spread in GHG emissions, acidification and eutrophication potential, human toxicity and ecotoxicity (mainly due to production of heavy metals in the manufacture of fibreglass and clinker) potential, and photochemical ozone creation potential.

Whereas the use of renewable energy as a power source in the pilot is associated with low environmental impacts, the construction materials used have been shown to have significant environmental impacts. These impacts can be reduced through the use of more environmentally friendly materials in the construction process. Kenya's renewable energy component in the grid electricity is currently 87%. In countries where the renewable energy component is less than in Kenya, it is expected that the environmental impacts of the project will be higher.

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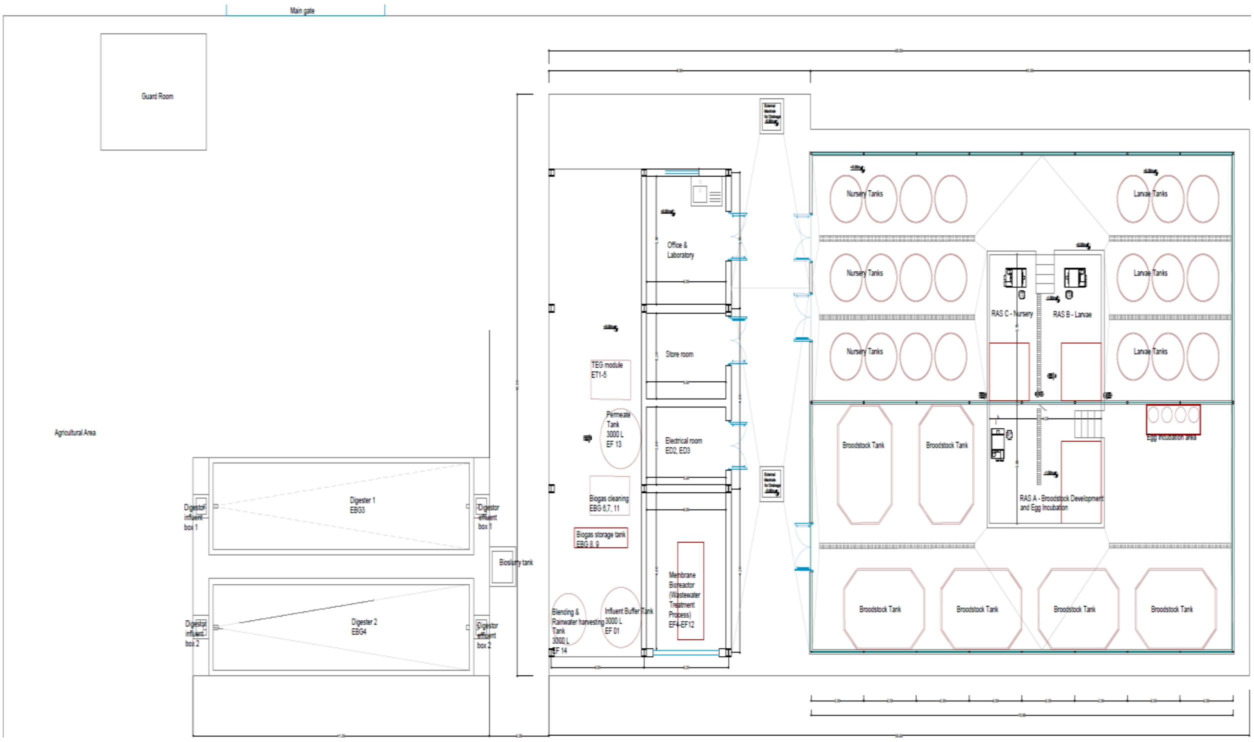
APPENDIX I: PLOT LAYOUT



APPENDIX II: EQUIPMENT POWER LIST

	Type	Voltage (V)	Power (kW)	Power @ working point (estimated)	Duty time @24h (estimated)	Energy consumption in kWh
Filter system			**1.745**			
	Peristaltic pump	220-240	0.25	100%	63%	3.78
	Centrifugal pump	220-240	0.23	50%	10%	0.28
	Centrifugal pump	24	0.04	25%	100%	0.24
	Diaphragm Pump	24	0.06	25%	80%	0.29
	Diaphragm Pump	24	0.06	25%	80%	0.29
	Air blower	220-240	0.13	100%	50%	1.56
	Air blower	220-240	0.215	100%	100%	5.16
	Centrifugal pump	220-240	0.5	100%	20%	2.40
	Ultraviolet Disinfection	220-240	0.08	100%	20%	0.38
	Sludge pump	24	0.04	50%	5%	0.02
	Mixer	24	0.04	50%	50%	0.24
	Control system	220-240	0.1	50%	100%	1.20
System A: Broodstock Development &			**3.17**			
	Water filter	220-240	0.15	100%	100%	3.60
	Centrifugal pump	220-240	1.00	100%	33%	8.00
	Ultraviolet Disinfection	220-240	0.08	100%	100%	1.92
	Solenoid valves	220-240	0.12	100%	100%	2.88
	Centrifugal pump	220-240	1.10	80%	100%	21.12
	Air blower	220-240	0.16	100%	100%	3.84
	Air blower	220-240	0.16	100%	100%	3.84
	Air blower	220-240	0.16	100%	100%	3.84
	Control system	220-240	0.12	100%	100%	2.88
	Control system	220-240	0.12	100%	100%	2.88
System B: Larvae & Weaning			**2.20**			
	Water filter	220-240	0.15	100%	100%	3.60
	Centrifugal pump	220-240	1.00	100%	33%	8.00
	Ultraviolet Disinfection	220-240	0.20	100%	100%	4.80
	Centrifugal pump	220-240	0.33	100%	100%	7.92
	Air blower	220-240	0.16	100%	100%	3.84
	Control system	220-240	0.12	100%	100%	2.88
	Control system	220-240	0.12	100%	100%	2.88

	Type	Voltage (V)	Power (kW)	Power @ working point (estimated)	Duty time @24h (estimated)	Energy consumption in kWh
	Control system	220-240	0.12	100%	100%	2.88
System C: Nursery			2.16			
	Water filter	220-240	0.15	100%	100%	3.60
	Centrifugal pump	220-240	1.00	100%	33%	8.00
	Centrifugal pump	220-240	0.33	100%	100%	7.92
	Air blower	220-240	0.16	100%	100%	3.84
	Air blower	220-240	0.16	100%	100%	3.84
	Control system	220-240	0.12	100%	100%	2.88
	Control system	220-240	0.12	100%	100%	2.88
	Control system	220-240	0.12	100%	100%	2.88
Additional			7.65			
	Cooling pump	220-240	0.5	100%	25%	3.00
	Gas compressor	220-240	1.5	100%	25%	9.00
	Pulping machining	220-240	2.2	100%	10%	5.28
	Control system	24	0.25	100%	100%	6.00
	Lights (LED)	220-240	1	100%	10%	2.40
	Socket (Computer, Basic Laboratory Equipment, Tools, etc)	220-240	3	50%	33%	11.88

APPENDIX III: BACKGROUND DATA SOURCES

Process	Database	Geographical region
Feed ingredients production		
Fish meal	Ecoinvent v3.5	Global
Maize grain production	Ecoinvent v3.5	Global
Rice production	Ecoinvent v3.5	Global
Soybean production	Ecoinvent v3.5	Global
Infrastructure		
Concrete	Ecoinvent v3.5	Global
Steel production	Ecoinvent v3.5	Global
Glass fibre	Ecoinvent v3.5	Global
Polyethylene	Ecoinvent v3.5	Global
Polyvinylchloride (PVC)	Ecoinvent v3.5	Global
Polypropylene	Ecoinvent v3.5	Global
Others	Ecoinvent v3.5	Global
Fertilizer production	Ecoinvent v3.5	Global
Tillage, ploughing	Ecoinvent v3.5	Global
Soda ash production	Ecoinvent v3.5	Global
Sulphuric acid production	Ecoinvent v3.5	Global
Diesel burned in agriculture machines	Ecoinvent v3.5	Global
Diesel burned in building machines	Ecoinvent v3.5	Global

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