Ecotechnology working paper 2018-1a [i]

Methodological considerations from a wastewater treatment case study in Kenya

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Abstract: Emergy methodology questions were raised during a case study where a Sugar factory effluent were treated in a pond system in the Lake Victoria watershed, and evaluated from a performance, cost and resource use perspective. This paper focus on the methodological questions, which were the following: (1) how should the emergy systems diagram be drawn when dealing with a system that is in the recycle loop? Is the wastewater on top in the energy hierarchy (highest transformity) or should the treatment system be located somewhere between the sugar factory on the energy hierarchy top and the dispersed nutrients low down in the energy hierarchy? (2) Rain emergy dominated the local renewable inputs. But how do rain contribute to the wastewater treatment in a pond system, other than as minor dilution? And is evapotranspiration a relevant measure of rain emergy in an aquatic system? (3) Since the case study had a microeconomic focus, is the historical ecosystem work behind lime a relevant item to include from the company's perspective? (4) the wastewater can be considered as a treatment problem, but also as a nutrient and water resource for e.g. irrigation. How does emergy accounting deal with the dualism of a get-rid-of-view and a get-use-of-view? (5) Is the, among some people, controversial maximum empower theory needed for the evaluation of the system, or is the less controversial energy hierarchy theory sufficient for the interpretation? (6) Does the emergy evaluation add any information regarding the sustainability of the pond system?

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[i] This manuscript was originally submitted in January 2008 to the proceedings of the conference Emergy Synthesis 5: Theory and Applications of the Emergy Methodology. Fifth Biennial Emergy Research Conference, at the Center for Environmental Policy, University of Florida, Gainesville, Florida, USA, January, 2008. It was, however, lost in the peer review process due to unclear reasons. Since it contained some interesting diagrams not published afterwards it is here published as a working paper, planned for further refinement. The manuscript was based on an abstract submission and a poster presentation at the conference.

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Introduction

Emergy methodology questions were raised during a case study where a Sugar factory effluent were treated in a pond system in the Kenyan part of the Lake Victoria watershed, and evaluated from a performance, cost and resource use perspective, in both monetary and emergy terms. This paper addresses these methodological questions, which were the following:

(1) how should the emergy systems diagram be drawn when dealing with a system that is in the recycle loop?

(2) how do rain contribute to the wastewater treatment in a pond system?

(3) is the historical ecosystem work behind lime a relevant item to include from the company's perspective?

(4) How does emergy accounting deal with the dualism of a get-rid-of-view and a get-use-of-view?

(5) Is the controversial maximum empower theory needed for the evaluation of the system, or is the less controversial energy hierarchy theory sufficient for the interpretation?

(6) Does the emergy evaluation add any information regarding the sustainability of the pond system?

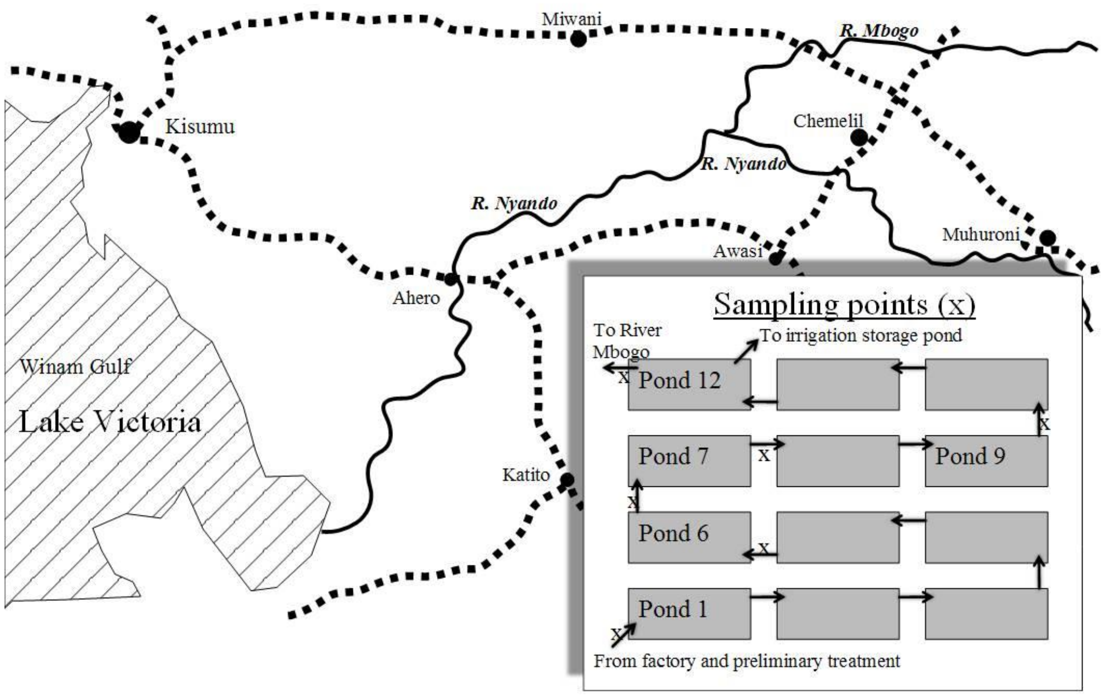

Figure 1. Location of Chemelil Sugar Company Ltd in the Nyando River Basin, Nyanza province, western Kenya, and at lower right, the stabilization pond wastewater treatment system receiving the sugar factory effluent. The preliminary treatment before the pond system consisted of pH-regulation with lime, a grease trap and a grit removal unit.

In the case study by Grönlund et al (2007) the performance of the existing wastewater treatment system were assessed to not meet the WHO wastewater treatment standards for COD. Suggestions were given how more effective management could be achieved, by changes in the liming regime and decrease the addition of dried microorganisms, so called microstarter. The management suggestions were at the same time cutting costs for the company. These management improvements were, however, not expected to fully reach the WHO standards. Therefore complementary treatment was suggested. Since land costs in the area were low, land demanding treatment using a higher degree of free ecosystem was suggested, e.g. a construced wetland. The choice of treatment was suggested to be guided by emergy accounting which reveals the local environmental contribution.

Methodological considerations

<u>(1) System diagramming of emergy in the recycle loop</u>

How should the emergy systems diagram be drawn when dealing with a system that is in the recycle loop? Is the wastewater on top in the energy hierarchy (highest transformity) or should the treatment system be located somewhere between the sugar factory on the energy hierarchy top and the dispersed nutrients low down in the energy hierarchy?

This is an area of interesting confusion. Normally, systems diagrams in emergy accounting are pictured according to the principle shown in Figure 2, where the wanted outcome (in this case treated wastewater) is always considered to have the highest transformity, and is therefore leaving the diagram to the right. As a principle, the systems diagram show the hierarchy of energy transformations from left to right in the picture, where the highest transformities (indicating the highest position in the energy hierarchy) are found at the right side. A common interpretation of this is that the product to the right has a higher quality than the parts that generated it (Odum1996). This type of systems diagram has been used in other emergy wastewater treatment papers such as Nelson et al. (2001), Geber and Björklund (2002), Björklund et al. (2001), Ko et al. (2001), and Grönlund et al. (2004). However, it is not evident that this is the best, or most proper, way to draw the diagram for waste products, as e.g. wastewater. One can argue that the wastewater is in the "down slope" of the energy hierarchy. Treating the wastewater further would not increase the transformity, but decrease it. A resulting system diagram would be the one shown in Figure 3, where the estimated transformity of the wastewater is lower than the purchased materials and fuels, and it is therefore placed nearby to the left of this item. The concentrations of the unwanted substances in the wastewater are decreasing during the treatment process, and the transformity of the treated wastewater is therefore considered to be lower than that of the raw wastewater. If the wastewater is considered to carry all the emergy from the sugar factory, Figure 4 may be an option. This type of view on systems diagrams we believe has some support in the suggestion by Odum (2001) of a sixth thermodynamic law regarding matter distribution.

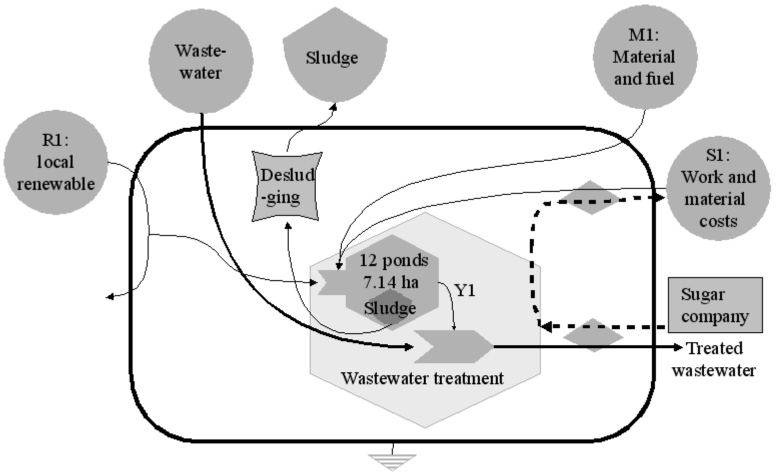

Figure 2. Conceptual diagram of the existing pond treatment system. Second law (of thermodynamics) depreciation flows from each energy transformation in the figure are aggregated as a sink symbol at the bottom of the figure.

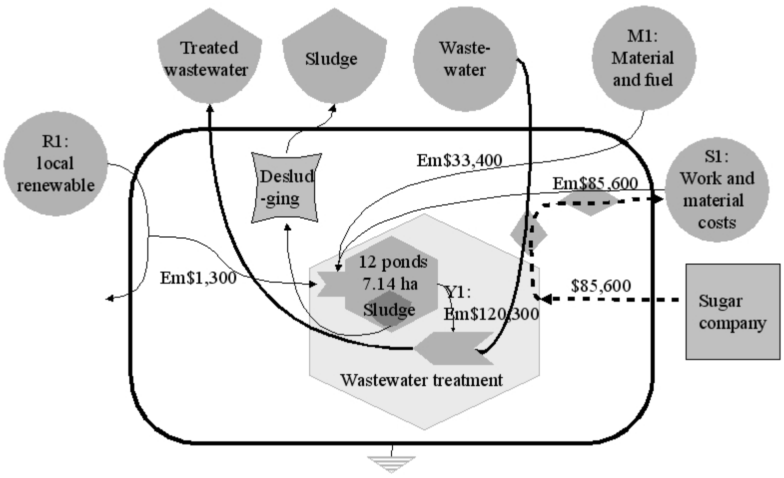

Figure 3. Alternative representation of the wastewater flow in systems diagrams. The wastewater is here considered to have a transformity higher than the sludge, but lower than the material and fuel import.

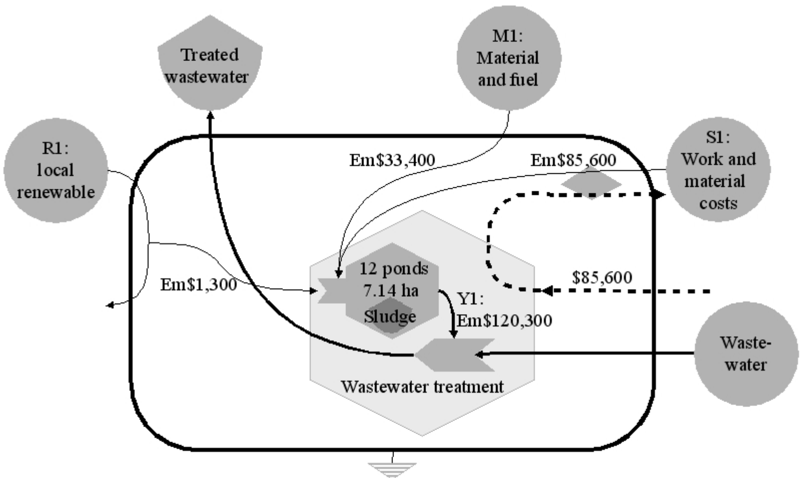

Figure 4. Alternative representation of the wastewater flow in systems diagrams. The wastewater is here considered to have the highest transformity in the picture.

(2) Meaning of rain emergy representing ecosystem work?

Rain emergy dominated the local renewable inputs. But how does rain contribute to the wastewater treatment in a pond system, other than as minor dilution? And is evapotranspiration a relevant measure of rain emergy in an aquatic system?

In general, emergy analysis differs from many other methods in that it does not always split up a sum for allocation to separate uses (as is common in economic calculations and life cycle assessment calculations). Instead, the allocated flows are sometimes allowed to carry the whole inflow sum to all branches (called co-products in emergy terminology). A common example is that the wool and the meat of a sheep are considered as co-products, and are each allowed to carry all the emergy it took to produce the sheep. If two such branches meet each other again they can not be summed. This is the case with the sun energy which causes both the wind energy and the rain energy as co-products. Therefore, they are not allowed to sum up in an emergy analysis, unless the rain for example comes from another part of the biosphere than the one where the sunlight was counted. In practice, the largest inflow of renewable energy is counted and represents the others, more as local "biospheric work" rather than just the energy content of the largest flow. In this case study, the rain energy was the largest, and was therefore representing all other local renewable flows. A problem, however, is that it is not easy to identify what ecosystem work the energy in rain performs in oxidation ponds. The sun energy has a more obvious role in the oxidation ponds, as it drives the photosynthesis and affects the temperature. Wind energy is also obviously engaged in temperature regulation and also evaporation from the ponds. But the rain - does it really contribute any ecosystem work to the ponds as they are already an aquatic environment? It dilutes the wastewater to some extent, but otherwise?

Often in emergy calculations evapotranspiration (EVT) is representing the use of rain for the ecosystem performance. This makes more sense in terrestrial ecosystems than aquatic ones. In the case study the authors chose to use the energy in the rainfall, calculated as the chemical difference between rainwater and sea water, instead of the more commonly used evaporation. Even more accurate would have been to use the difference between the chemical potential in the rain and the treatment wastewater leaving pond 12, but there was no access to such data.

Hussey and Odum (1991) conclude that the role of EVT in an estuary is the major pathway of releasing water from the sediments through the water transportation work by helophytes, and thereby also oxidize the sediments.

Another consideration is that rain carries two types of energy, the chemical potential energy and the geopotential energy. A question is whether they are allowed to add or if they also represent each other as co-products? The latter seems to be the common approach in emergy analysis. In the paper, the geopotential used by the pond system was less than 5 meters, resulting in a contribution less than 0.5% of the rain chemical energy.

Maybe the plant physiological concept of water potential, including osmotic, pressure and other potentials, could shed some light on this question.

(3) Historical ecosystem work in a microeconomic context?

Since the case study had a microeconomic focus, is the historical ecosystem work behind lime a relevant item to include from the company's perspective?

The Emergy evaluation (EmEv) included the imported ecosystem work, inherent in the goods purchased to the treatment systems. This fact emphasizes the very different character between conventional microeconomic analysis' and EmEv. Conventional microeconomic evaluations consider scarce resources, whereas EmEv is a systems analysis, including flows whether they are limited or not. In this case study, the ecosystem work behind the lime was considerable and of the same order as the monetary flows (27% of the total 120,300 Em$ given for the ponds). This is useful information from a macroeconomic point of view. It may also be valuable information from a microeconomic perspective in the economic system where the lime is mined, since it highlights the use of a natural resource that is not rapidly replenished. From the company's microeconomic view such aspects probably do not matter very much, and therefore the relatively high Emdollar value of lime would most likely be ignored with this perspective.

(4) Get-rid-of view vs. get-use-of-view?

The wastewater can be considered as a treatment problem, but also as a nutrient and water resource for e.g. irrigation. How does emergy accounting deal with the dualism of a get-rid-of-view and a get-use-of-view?

The wastewater treatment system was analyzed as a "get-rid-of" system, but the wastewater can also be seen as a nutrient resource promoting biomass production in receiving ecosystems. As such, the ecosystem services behind the productivity of the system chosen to process the nutrients should be taken into account. That could be an agricultural irrigation system (e.g. sugar cane), where a crop absorbs the nutrients, a wetland where papyrus or fodder grass is harvested, a high-rate algae pond (HRAP) with a crop of microalgae, or fish production in a series of aquaculture ponds. In the case study this was not included. An interesting question for further research is if emergy calculations can contribute also to the difficult allocation problem of "get-rid-of" wastewater treatment and the probably larger system window of "getting-use-of" wastewater treatment.

(5) Maximum empower needed for interpretation?

Is the, among some people, controversial maximum empower theory needed for the evaluation of the system, or is the less controversial energy hierarchy theory sufficient for the interpretation?

Still a young method, scientists working with emergy analysis have not yet fully found the semantic interpretation of the results calculated. The developers of the emergy concept, H.T. Odum and co-workers, often interpreted the results in an evolutionary context of the "maximum empower" concept, suggested as a fourth thermodynamic law. A recent mathematical formulation of that hypothesis (Giannantoni 2002), widens the possibility to test this hypothesis. However, in the case study by Grönlund et al. (2007), the "maximum empower" hypothesis was not considered. The main interpretation used instead was that the results from the emergy analysis can be viewed as the relative importance of different items to the systems total performance.

(6) Sustainability and emergy

Does the emergy evaluation add any information regarding the sustainability of the pond system?

In the paper of Grönlund et al. (2007) the Emergy sustainability index (ESI) by Brown & Uligati (1997) was calculated. However, there were no relevant investigations in literature to compare the index with, and it therefore did not give much information.

From a systems ecology context sustainable development may be interpreted as to sustain in the larger system over time (Jansson and Jansson 1994). This definition makes the concept totally context dependent. From the company's perspective, which is the next larger scale for the pond system, the factory needs a wastewater treatment system that is cheap but good enough to meet the national standards. Since the contribution of free local environmental work is area dependent, cheap land costs implies a wastewater treatment solution using much of the local free environmental work will be cost effective.

From the society's perspective not just the cost-effectiveness is important, but also the general knowledge of connections to the resource base, including the regenerative side. I figure 5 the famous figure 3.1 in Odum (1996) is overlayed by the in sustainability discussions common "triple-bottom-line", see e.g. Klang et al (2003). The economic hierarchical levels are defined as the ones were money flows, and the ecological levels are the ones below the economic. The border can of course be moved leftwards depending on the definition of economy, if it deals only with levels where money flows or if the definition is extended also to other scarce resources.

The hierarchical levels above the economic level are defined as the social sustainability levels. Emergy evaluations of these levels have so far hardly been done in emergy literature, and they are maybe also too complex to aggregate in emergy diagrams in practice. However, social features important for the stability, competitiveness, and fitness in the larger system, may in the future be quantified in information terms (bits) and then converted to emergy by an emergy per bit ratio.

Figure 5 illustrates that emergy evaluation has a potential to measure all three aspects generally discussed under "sustainability", on the same counting base: emergy. It also clarifies why focusing only on economic aspects leads to a severe risk of sub-optimization. It could really be argued that preserving economy is not of interest per se. Rather sustainability in the larger system perspective could be considered as ensuring the human needs (social values) dependent on transformed ecological values.

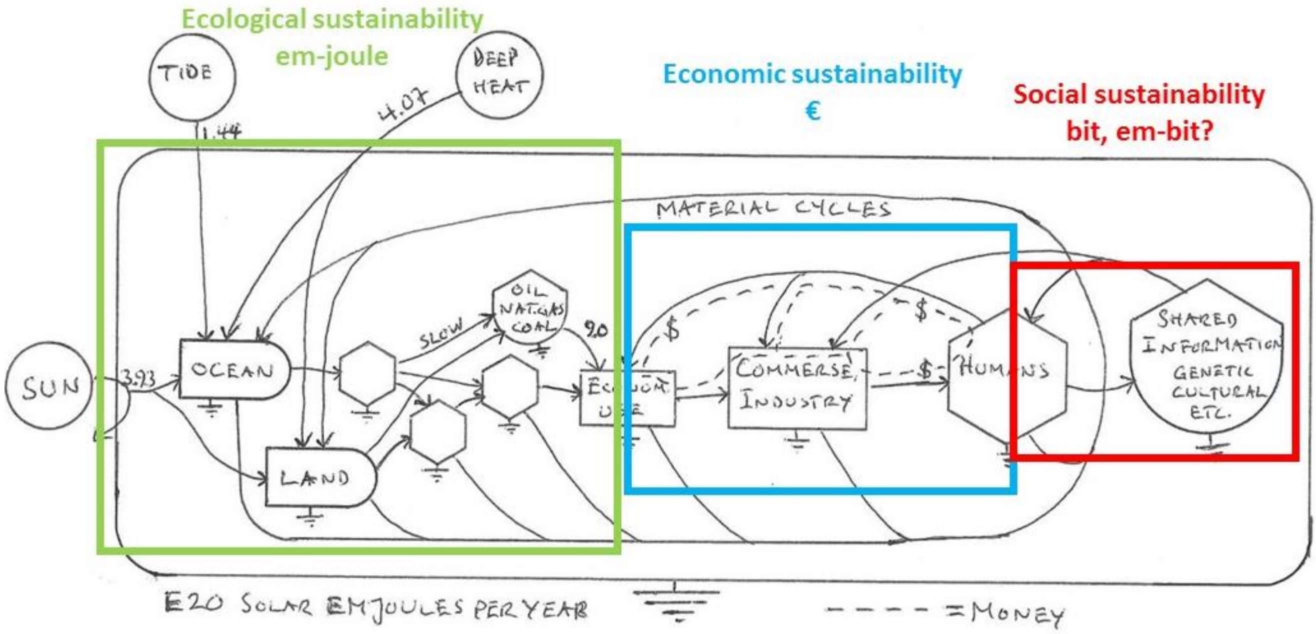

Figure 5. The "triple-bottom-line" applied to Odum (1996), figure 3.1.

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[iii] The manuscript was rejected from Ecological engineering, since the reviewers could not agree if it was a good or bad paper. Finally the manuscript was published as: Grönlund E, Billgren C, Tonderski KS, Raburu PO. 2017. Emergy Assessment of a Wastewater Treatment Pond System in the Lake Victoria Basin. *Journal of Environmental Accounting and Management* 5: 11-26.

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