Sustainable Operation: Developing a Training Concept for an Energy-Water-Food System in St. Rupert Mayer, Zimbabwe

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ABSTRACT

Water, energy, and food are essential for human well-being, poverty reduction, and sustainable development; meanwhile, their demand is projected to increase significantly in the next decades. Linking the three sectors through an Energy-Water-Food System (EWFS) may have a synergetic impact. Such a system is being tested in St. Rupert Mayer (SRM), Zimbabwe, where supervision and technical support from the Technical University of Munich (TUM) is still highly needed. For a more sustainable operation, a training concept was developed and implemented to reinforce and expand local expertise and to socially integrate the EWFS. This concept consists of five key modules; its implementation and testing phases took place on-site from January to March 2020. Graphical nature and bottom-up approach proved essential for the acceptance. This training concept and the findings of its implementation will soon be replicated in other similar villages in Rwanda and later be taken as a blueprint for similar EWFS projects in the global south.

KEYWORDS: Sustainable operation, Energy-Water-Food system, Decentralized energy systems, Training concept, Operation and maintenance manual, Global south.

INTRODUCTION

Due to the increasing world population, which is predicted to reach 9 billion in 2050, accomplishing global food and water security would be even more difficult and stressful for the environment than nowadays [1]. Increasing food production requires more water and higher energy generation, which constitutes higher water demand. Since those three crucial sectors are highly interdependent, an Energy-Water-Food System (EWFS) might be a step in the right direction of achieving economic development and social progress while protecting the environment.

The main concept of an EWFS is to use the energy present in the solar radiation, either producing electricity through PV panels, to supply water pumps and household loads, or heating up water through solar collectors, to subsequently cover some heating demand. Some systems can combine both types of energy transformation (electricity and heat production). If the energy captured exceeds the current demand, the excess energy can be stored in an energy storage

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system (battery, water tank, hot water tank) to supply the system when the natural resource is not available. In addition, a diesel engine generator can be set as a backup power supply and be included as part of a decentralized hybrid micro-grid. The water (either cold or hot) can be used for drinking, cooking, heating, and for agricultural purposes. As a result, locals can do small-scale agriculture in the dry season and are less dependent on external food purchase. By irrigating and cultivating the fields efficiently over the year, the produced crops can not only meet self-consumption, but they can also be sold to generate an income and establish an agribusiness.

The agricultural and harvest waste, along with animal manure from livestock farming, can then be used to produce biogas in a biogas digester. Biogas can be used for cooking purposes or to run a backup generator to produce sustainable electricity and complete the loop in the EWFS. Briefly summarized, the most important benefits of an EWFS are a reliable electricity and water supply, less dependency on external food purchase, additional income by selling agricultural products and more job opportunities for locals. This is how EWFS contributes to the achievement of the SDGs in multiple ways [2].

The high risk and locals' weak purchase abilities make investors reluctant to invest in rural areas. However, a big part of the rural areas' economy relies on agriculture, that is why creating an agribusiness could lower the risk for investors and empower the locals. Another benefit of having a business module in the EWFS is that the locals might develop deeper responsibility towards the project. That will increase the chances of them performing proper maintenance on the system, which is a key factor in its sustainability; since harsh environments, usually found in rural areas, make projects more prone to failure if not properly operated and maintained.

In order to make the operation of an EWFS sustainable, operators are needed to operate, maintain and troubleshoot the system. The primary goals of maintenance are to mitigate small problems from becoming huge failures and to ensure that the system operates at full potential, so none of the valuable natural resources are wasted [3]. In previous studies [4] a systematic approach to operation, maintenance and troubleshooting was proposed by regulating the tasks and roles of the different operators involved. This should help local operators acquire the needed technical and organizational skills and allow effective tracking of performed tasks, maintenance schedules and failures registration. To test this approach practically a case study was performed on the EWFS in St. Rupert Mayer (SRM), Zimbabwe. The biggest challenges that the EWFS installed in SRM was facing prior to this study were improper operation, inadequate maintenance, and poor decision-making skills regarding the technical aspect of the system[5, 6]. This made SRM a great location to test the developed training concept and its implementation. If correctly introduced, the training should make the importance of maintenance for the sustainability of the EWFS clear to all the stakeholders.

METHODS

The training concept was mainly developed based on the authors' practical experience in the field of technical training and their experiences on-site in SRM. The TUM School of Education was also consulted in the process to ensure efficient teaching methods. Nevertheless, the training concept was kept as general as possible to serve as a blueprint for other EWFSs. The model is oriented towards a defined organization of the EWFS stakeholders: Community, operators and farm manager. It suggests a bottom-up approach and gives space to identify beneficial opportunities through the habits of all the stakeholders.

The present training concept considers the three main technical parts of the EWFS: Electricity (PV panels, batteries and inverters), water (Pump controller and pump unit) and the biogas part (Digester and gas storage). The food part of the EWFS is implicitly covered in the water and biogas parts, but all the other characteristic components of the agribusiness are not in the scope of the training concept.

For ensuring a long term reliable and self-sufficient (sustainable) operation of the EWFS, the training concept was divided into five modules: Regularization of the operation and maintenance (O&M) tasks, problem identification and solving (troubleshooting), monitoring of the O&M and troubleshooting tasks, EWFS management, and knowledge transfer. The first three modules address mainly the operators and technicians, while the two last ones focus on the farm manager and the future stakeholders. The five modules were developed in each case for all the three EWFS' parts mentioned above (electricity, water, biogas).

To increase the chances of a successful adaption of the O&M tasks, standardized periodical routines were introduced through easy-to-follow manuals for each part of the EWFS (electricity, water, biogas). Developing training material in the local language is, generally, not feasible and in many cases the operators have no English skills. Therefore, the manuals were designed to be self-explanatory using mainly visual content, such as diagrams, pictures, or simple drawings. When text was unavoidable, the language barrier was reduced by implementing certain features, such as: clear and short tasks coupled with demonstrative figures, words with defined colors depending on their purpose, highlighted keywords, and underlined warnings. Since the manuals do not have a commercial purpose, references were not used to avoid any unnecessary confusion. The manuals directed a great focus towards maintenance, given that it lowers the rate of failures, when done properly.

Once a problem occurs and therefore the system either underperforms or fails completely, the troubleshooting module should be used to determine the needed actions. The Problem Inspection and Troubleshooting manual helps the farm manager at receiving information from the operators, guiding them in solving problems that may arise and finding their cause. To this aim, this manual consists of two parts. The Problem Inspection part lists the possible abnormalities that can be detected by the operators and, for each of them, searches in a logical and systematic way for the source of the problem. On the other hand, the troubleshooting part guides the farm manager into the identification of the final cause and once identified, explains how to solve it, and the measures needed to prevent it from happening again. In some cases, this part redirects to the Maintenance part of the O&M Manual. In case the problem is too complicated or needs parts that are not available on-site, contact information of the needed technical support is provided to proceed forward with reparations.

To keep track of the operation and follow up possible events that might lead to operational faults or general problems, the training concept includes three protocols. The first one records the periodical procedures, (e.g. stirring frequency of the digester, cleaning of the solar panels) and includes a field to note any deviations from the regular procedures or normal operating conditions. The second protocol is used when maintenance tasks take place, it also documents any abnormal occurrences. Lastly, the third protocol documents problems, their most possible cause and how they were solved.

The farm manager should undergo intensive training to ensure he has a sufficient understanding of the EWFS and the interactions between its components, not only for operational purposes but also for future changes or important decisions regarding the system. For the specific case of the biogas, a compendium of the available resources suitable for biogas production should be supplied, as well as well-defined rules to plan the feedstock collection and feeding according to the resource availability. A technical manual, which considers the management of the entire EWFS under the farm manager's responsibility, should provide the needed support for the farm manager to develop a deeper and more scientific understanding of the EWFS.

All these manuals serve as a part of the last module of the training concept, the knowledge transfer. Although it contains technical vocabulary, the manuals are kept simple using diagrams and graphics. Finally, self- training video material should enable knowledge transfer in a reliable way and independently of the expertise of the current or former staff. The audiovisual media consists of several short videos showing how to carry out the periodical and maintenance tasks.

According to the definition of a bottom-up approach, the development and implementation of some modules of the training concept should overlap at some points. That is why the on-site work consisted of four phases: Observation (of the regular tasks' execution), Testing (of the pre-elaborated training material), Fitting and further development (of the material including the stakeholders' feedback), and Implementation.

RESULTS

The work on-site was successfully completed within six weeks. Through the observation phase, a better understanding of the community's dynamic was gained and the stakeholders got more familiar with the trainers. In this first part, the state of some components, which were thought to be missing or available, was recognized. The training concept and its components were adjusted correspondingly to proceed to the next step, the testing phase. During this phase, the high proportion of visual content, the simplicity of the diagrams, and the detailed step-by-step structure were found to be a key role at comprehending the O&M manuals and the protocols.

Later on, the implementation of the final version of the printed material in its proper format (e.g. hand size friendly format, spirally bound, laminated pages, color printed) proved to be helpful for the operator in getting familiar with the newly introduced routines and procedures; it also increased their acceptance of the material itself. Another accomplishment in this phase was the production of self-training audiovisual material for the O&M tasks of the biogas plant with the operators as protagonists. The operators did not need any further explanation to perform the tasks in the video, which serves as an evidence for the comprehension of the training concept.

Following a bottom-up approach, the training was carried out by performing the new routines and protocols together with the involved staff. They kept repeating them under supervision until they felt confident enough to perform it alone, or were observed to be ready to do so by the trainers. This reduced the impression to be introducing something foreign, leading to the acceptance of the concept. Some variations in generation and consumption patterns in SRM that influence the EWFS were acknowledged through the close collaboration between the trainers and trainees, which were essential information to develop the appropriate Supervising & Planning concept for the farm manager.

In contrast to the electric system, fluctuations in the energy source of the biogas system (i.e. the feedstock) strongly influences the O&M routine. Identifying the source of those fluctuations enabled the creation of a plan for collecting the feedstock and a schedule for using it, which involved many stakeholders and were supervised by the farm manager. This plan was created based on the projected feedstock availability for the next twelve months. However, to keep it flexible, “golden rules" were established, such as the way and timeframe in which the load can be increased. In addition, a quick tool to estimate the biogas production depending on the feedstock availability was developed and designed to be used by the farm manager. This was vital for the SRM case to conceive a gas collection plan that couples generation and consumption regardless of any storage volume constraints (i.e. a limited amount of gas bags).

Through the implementation of the training concept in SRM, notable improvements in the system’s performance were observed. The biogas production was increased by 50% within four weeks, water production was enhanced after discovering many leakages in the piping network and fixing them, and the newly implemented battery management practice protects the batteries from complete discharge that shortens their lifetime.

DISCUSSION

From the experience gained in SRM, developing a training concept for an EWFS can be divided into two main stages: off-site development and on-site implementation. Each stage had its challenges. In the first stage, a challenge arose when choosing how many details to include for each task and the needed depth of its explanation, since an accurate assessment of the technicians' knowledge level was not available. Therefore, an intensive on-site evaluation before starting the off-site development would be helpful. When developing the graphic content, technical-oriented engineers might face troubles translating complex tasks or concepts into simple illustrative figures. In this case, this was mitigated by working closely with professionals in the adult pedagogy field, as well as with a graphic designer, ensuring the effectiveness and clarity of the illustration without compromising their technical integrity.

The difficulty of defining maintenance tasks varied depending on the assets. For some equipment, such as the PV panels, the maintenance tasks were mostly independent of the location and the manufacturer. This made developing the related material easier than, for example, for the biogas digester, since its maintenance actions depend highly on the site’s conditions and type of available feedstock.

When it comes to the activities done on site, witnessing how the operators perform their routine enabled understanding the operators’ way of thinking and thus, helped in finding the proper way to friendly introduce the new procedures and structures. Some facts regarding the routines and protocols, which were not noticed in the development stage, were brought to light through observation. For example, having at least one operator for each system (PV, water pump, biogas) with sufficient English skills proved to be essential for the success of the testing part; especially for some maintenance tasks in which oral explanations were unavoidable. This emphasized the need to achieve a 100% graphical content in the O&M manual for future similar projects. An important feature of the O&M manual was its rigorous explanations, which had to be flexible enough to easily integrate the operators' feedback gained from the on-site testing.

Working hand in hand with the operators had other benefits than just the friendly introduction of the new routines and procedures. For instance, it was possible to assess if the operators always had the necessary tools and materials, in the proper place, to perform tasks when needed. Alongside the friendly introduction and observation, it was important to have the final version of the training material printed in the proper format (i.e. size, colors and casing) to ensure a smooth implementation of the training material. It might seem irrelevant, but it is something worth considering in places with no access to electricity let alone nearby printing facilities, which is the case for most rural areas.

As stated in the previous section, the newly introduced routines were performed together with the operators until they expressed their confidence in performing them independently. Nevertheless, for future implementations it would be more sensible to assess their readiness in a more objective and structured way through indicators of acceptance and comprehension. These indicators must be defined clearly, and a certain threshold should be introduced; when this threshold is reached the training can be considered completed successfully.

It is important to make all stakeholders clear the significance of proper documentation on purchase and installation dates of the different assets. This is not a common practice in rural areas but strongly contributes to the project's sustainability, since based on that data appropriate maintenance schedules can be developed. The present training concept did not include any protocol to keep track of those relevant dates, but it is recommended for future similar projects, especially if the equipment is about to be bought or if the project administrator changes often.

An important aspect to consider is the social acceptance of the training concept. In the specific case of SRM, the mission's superior is the community leader and has the final say in all major decisions regarding the mission. A huge challenge when introducing the EWFS concept in rural areas is to establish the suggested organization for the EWFS stakeholders (i.e. farm manager, technicians and operators) in the community hierarchy. It is therefore crucial to discuss the EWFS stakeholders' coordination with the community leader(s) and the roles of everyone involved. If a compromise between preserving the local social-ecosystem and maximizing the functionality of each stakeholder in the EWFS is found, a long-term cooperation is then ensured.

Even if the EWFS system and its training concept are socially accepted, incentivizing the stakeholder to perform the extra-work within the same number of working hours can still be arduous. For that reason, it is crucial to remind them and the community of the mid- and long-term advantages of their extra-work and commitment. An increase in pay also proved greatly beneficial in strengthening their drive and motivation, therefore efforts to achieve this are strongly recommended.

CONCLUSIONS

The proposed training concept has proven its contribution in the pursuit of sustainable operation. During the on-site implementation phase, the biogas production doubled and the irrigation effort decreased. Mid-term improvements in the system's operation caused by the methodologies and protocols introduced by the training concept are already being noticed: A steady power supply for the fridges guarantees sanitary conditions for the food that the boarding students get every day at the dining hall. Another improvement, which is caused by the reliable irrigation, is that the first harvest of the whole project's lifetime took place in early June, bringing in some revenues to the agribusiness. Also, the plan and rules for collecting and using the feedstock for the biogas are keeping the biogas production constant despite variations in the feedstock availability. That became essential during the Corona outbreak, since the main feedstock (Dining hall's food waste) is not being produced anymore and guarantying the biogas availability for the hospital's kitchen has become more crucial than ever.

Making the content of the training concept as graphical and self-explanatory as possible could be considered the most important feature to focus on in the development phase. What makes this feature crucial is the difficulty of developing a manual in the local language. Following a bottom-up approach to develop the concept on-site and implement it, showed several benefits: it enabled identification of the stakeholders needs, weaknesses of the concept were exposed and mitigated, it highlighted important stakeholders dynamics which are essential for the project's success, it also revealed ways to introduce the protocols in a more friendly way, and it strongly promoted the technical and social acceptance of the project.

Even with this work as a blueprint, it is important to keep the O&M manual meticulous in its explanations yet flexible enough to easily integrate the operators' feedback from the implementation phase. There is always room for improvement, such as defining the indicators of performance and managerial training of the farm manager to compliment the technical training from this work.

After complementing the training concept with the elements mentioned above, this training concept, its methodology and implementation should serve as a model that speeds up the adoption of structured operation and maintenance -and thus the social and technical sustainability- of EWFSs projects in rural areas. It is worth mentioning, that because of its strong dependency on the social aspect, this blueprint will always need adjustments to suit each community's specific dynamics and therefore work on-site might be different to the one showed here.

This work emphasizes that in these times it is essential to produce more with less, to satisfy the needs of the humankind without increasing the stress on natural resources.

REFERENCES

[1] Bergstrom *et al.*, "A Review of Solutions and Challenges to Addressing Human Population Growth and Global Climate Change," *Int. J. Clim. Change Impacts Responses*, vol. 4, Jan. 2013, doi: 10.18848/1835-7156/CGP/v04i03/37178.

[2] J. Winklmaier and S. Bazan Santos, "Promoting Rural Electrification in Sub-Saharan Africa: Least-Cost Modelling of Decentralized Energy-Water-Food Systems: Case Study of St. Rupert Mayer, Zimbabwe," in *Africa-EU Renewable Energy Research and Innovation Symposium 2018 (RERIS 2018)*, Cham, 2018, pp. 71–89.

[3] Richard (Doc) D. Palmer, *Maintenance Planning and Scheduling Handbook*. McGraw-Hill Professional, 2005.

[4] J. Hubert, J. Kingsley-Arthur, L. Leao Glória, M. Ruffieux, D. Sá, and F. Schroll, "Development of a training concept for an Energy-Water-Food business in the rural community of St. Rupert Mayer, Zimbabwe," Technical University of Munich, Munich, Germany, Internship report, Feb. 2019.

[5] A. P. Corredor Barrera, "Development and implementation of a training concept for a biogas plant in St. Rupert Mayer, Zimbabwe," Munich, Germany, Internship Report, Apr. 2020.

[6] N. Faza'a, A. S. Abouzari, and S. Guenther, "Development of an operations and maintenance manual for the Energy-Water system in the community of St. Rupert Mayer, Zimbabwe," Technical University of Munich, Project lab report, Jul. 2019.