A Participatory Hybrid Decision Support Modelling Framework for Industrial Symbiosis

O. Chen[1], B. Evans[2], M. Khoury[3], L. Vamvakeridou-Lyroudia[4], N. Mustafee[5], A. S. Chen[6], S. Djordjević[7], D. A. Savić[8]
[1,2,3,4,6,7,8] Centre for Water Systems, University of Exeter. Harrison Building, North Park Road, Exeter, EX4 4QF, UK.
[1,5] Centre for Simulation, Analytics and Modelling, Business School, University of Exeter. Xfi Building, University of Exeter, Rennes Drive, Exeter, EX4 4ST, UK.
[4,8] KWR Water Research Institute. Groningenhaven 7, P.O. Box 1072, 3430 BB Nieuwegein, the Netherlands.
[1]*c.chen2@exeter.ac.uk*

Keywords: Agent Based Simulation (ABS), Discrete Event Simulation (DES), greenhouse, Multiple Criteria Decision Analysis (MCDA), Netherlands, System Dynamic (SD)

EXTENDED ABSTRACT

Introduction

Industrial symbiosis aims to realise synergistic possibilities amongst industries and/or businesses by leveraging their geographic proximity to achieve a collective approach to competitive advantage [1]. The proximity enables the exchange of water, energy, and material amongst the individual entities, wherein the waste and by-products of one industry become valuable resources/materials for another. Within the overarching symbiosis concept, the focus of our work is on valorising resources within the water cycle, which seeks to create value and increase sustainability in holistic dimensions, including economic, social, ecological, and environmental aspect. The concept regards wastewater not only a reusable resource but also a carrier for valuable energy and components to be reclaimed. Hence, the symbiosis promotes circular economy in various industrial settings and facilitates partnerships between business, water service providers, and authorities.

To establish innovative symbiosis amongst stakeholders, the demands and interests of the perspective stakeholders need to be fulfilled before the agreement on symbiosis is reached. However, the symbiosis is a new business model with many unknowns that cannot be easily learnt from existing systems. To address potential challenges and identify the benefits of the business model, efficient simulation tools particularly developed for supporting stakeholders in decision making for the symbiosis are needed but not widely available. Moreover, the scenarios of solution proposed by stakeholders in the symbiosis context may involve long-term and dynamic attributes with different priorities at various temporal stages, which are unable to be reflected adequately by existing tools. Therefore, the study tends to propose a novel modelling framework of symbiosis in water cycle context (**F-SWC)** for supporting decision making, with features as follows:

- **F-SWC is a participatory framework:** The framework aims to serve as a generic solution so that the symbiosis idea can be convinced and realised though the participation of stakeholders. Each symbiosis collaboration involves unique combination of stakeholders. The framework proposes the use of multiple participatory approaches, e.g., multiple criteria decision analysis (MCDA), qualitative system dynamics (QSD), to develop a consensus system view towards the symbiosis to convince the stakeholders with **collective advantages** and comprehensive assessment.
- **F-SWC is a hybrid modelling framework for decision support:** The modelling framework is mainly based on the combination of two parts of modelling: one part adopting a stakeholder participatory multiple criteria decision analysis (MCDA) and the other part implementing a hybrid simulation approach of operational research [2], which combines discrete-event simulation (DES), system dynamics (SD), and agent-based simulation (ABS). The hybrid modelling methodology will lead to a novel dynamic character regarding the criteria of the decision analysis, as well as optimisation of solution scenarios to deal with challenges and advantages foreseen by the modelling, which is more in line with the real situation of long-term solutions of the symbiosis.
- **F-SWC is a framework that focuses on the valorisation of the water cycle:** Industrial symbiosis seeks to enable collaboration amongst industries located in close proximity, through the exchange of water, energy, material, and by-products. The focus of the framework is on wastewater which may contain energy and nutrients.

The study has applied the F-SWC framework to a Dutch greenhouse case study to demonstrate the proof of concept. The results from the pilot application provide critical information to help stakeholders evaluate the investment and benefits of the conduct of the symbiosis business model in a full scale. The symbiosis of the Dutch greenhouse case involves not only the adoption of new technologies, namely advanced wastewater treatment, reclaimed water aquifer storage, and heat aquifer storage, but also an upcoming stricter national regulation about greenhouse discharge, i.e., zero emission. The symbiosis collaboration will offer collective advantages for responding to the change of regulation, which is more advantageous to the farmers than sorting out the challenge individually. The Dutch zero emission regulation will potentially cause significant impact on greenhouse industry worldwide in the future [3].

Methods and Materials

Figure 1 shows the framework of the hybrid modelling. The modelling dynamics are primarily reflected by the weights of MCDA, which may change over time according to the priorities regulated by the stakeholders' targets. The MCDA is followed by the ABS module, the number of agents (i.e., A1, A2, …An) in ABS will be equivalent to the number of criteria (i.e., C1, C2, …Cn) in MCDA. In Figure 1, we assume only three criteria of MCDA (i.e., also three agents in the ABS module). The ABS allows the agents to behave individually, i.e., to calculate its own performance, and to describe the necessary interactions between the agents. The main symbiosis process model is established as DES structure in A1, which means the DES is a sub-model in the ABS. We select DES approach because the symbiosis system involves process in the water cycle, i.e., a sequence of operations being performed across entities. The DES seeks to achieve optimisation, which analyses utilisation of resources, time spent in the system, waiting times, system throughput, and bottlenecks [2]. Since the proposed scenarios will be on the long-term basis, for example 15 years, the model will run through ABS year by year. At each year, a system performance will be provided, then SD module will dynamically decide whether and how the weights of MCDA for the next year will be adjusted based on the system performance to reach the periodic target.

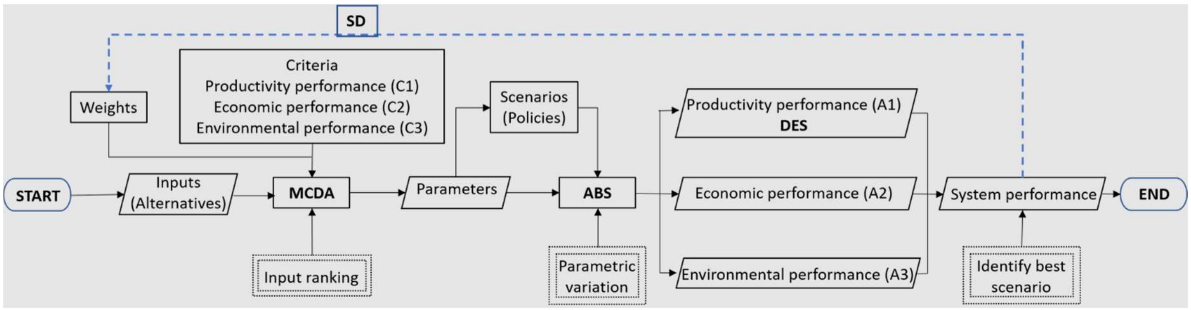

Figure 1. The framework of the participatory hybrid decision support modelling

Figure 2 shows the planned symbiosis system of 60 greenhouses in Vlot. Currently, these greenhouses only recycle a small proportion of water used, by collecting and treating drain water. The new symbiosis system includes (1) 100% drain water reuse (i.e., zero emission); (2) a feasibility assessment of using excess heat and CO2 from waste incineration plant to replace current gas boiler system; and (3) the external water supply of treated wastewater from other industry (i.e., sugar factory). Besides, in order to cope with seasonal fluctuations in water supply (i.e., rainfall) and heat demand, balance is planned to be achieved through storing these excessive resources, i.e., aquifer storage and recovery (ASR) system for excessive treated water, and aquifer energy storage (HT-ATES) system for excessive heat.

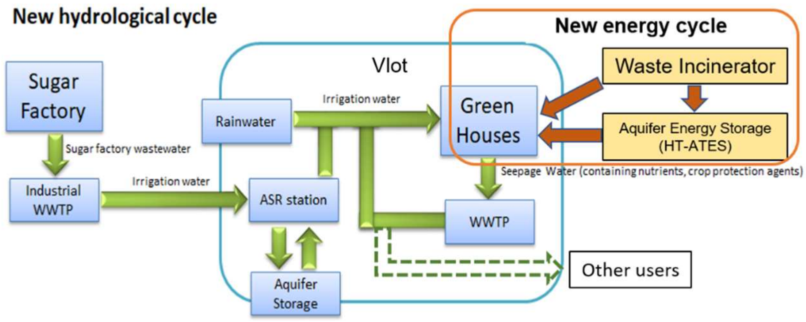

Figure 2. The outline of symbiosis system for the Dutch case in Vlot

Results and Conclusions

The study is part of and funded by the ongoing EC H2020 ULTIMATE project (GA 869318), which aims to demonstrate solutions for the whole value chain and to strengthen synergies between industries and water utilities. This is an ongoing study that the pilot plant for treating drain water and feasibility assessment of aquifer energy storage system are being constructed. Once the pilot plant is running in full capacity, the continuous records will help us improve the settings of the hybrid modelling to obtain more accurate assessment regarding the benefits of symbiosis, which will enable evidence-based decision making to achieve the long-term vision of zero emission.

REFERENCES

[1] Chertow, Marian R. "Industrial symbiosis: literature and taxonomy." Annual review of energy and the environment 25, no. 1 (2000): 313-337. [2] Eldabi, T. A., et al. "Hybrid simulation modelling in operational research: A state-of-the-art review." *European Journal of Operational Research* 278, no. 3 (2019): 721-737. [3] van der Salm, et al. "Minimising emissions to water bodies from NW European greenhouses; with focus on Dutch vegetable cultivation." *Agricultural Water Management* 242 (2020).