# Techno-economic assessment of Industrial Symbiosis interactions based on Mass Flow Cost Accounting methodology coupled with cost/benefit analysis

I. Julian[1,*], E. Wallin[2], M. Vendt[2], L. Ventura[1], S. Ascaso[1], R. Fornell[2], M. Gomez-Perez[1,*]

[1]CIRCE - Technology Center for Energy Resources and Consumption, Parque Empresarial Dinamiza, Ave. Ranillas 3D, 1st Floor, 50018 Zaragoza, Spain

[2]RISE Research Institutes of Sweden, Sven Hultins plats 5, SE-412 58 Göteborg, Sweden

Presenting author email: magomez@fcirce.es
Keywords: industrial symbiosis, circular economy, waste utilization, techno-economic assessment

**Introduction**

Industrial symbiosis (IS) solutions represent a key factor to boost circular economy models. IS exchanges often involve the integration of different resource types, such as, energy, water, power, carbon, by-products or wastes. Under certain circumstances, IS solutions may have a very positive impact on the overall waste and emissions reduction at industrial park level and may potentially represent a favourable business case scenario for the involved stakeholders. Given the eventually high costs of waste management (i.e., transportation, landfilling, development of recycling/valorisation strategies) and the increasingly restricting legislation related to their emission, which imposes severe penalties to the companies that exceed the permitted emission rates, IS emerges as a necessary long-term player for both sustainability and stakeholders economy.

However, the frequently required upgrade of the waste flows to be employed as raw materials in others' processes drives to the adoption of investment costs in technological solutions for such upgrading. Together with this, the different companies' interest and site-specific regulations hamper the implementation of a number of IS relations. In order to promote IS actions, this work aims to establish guidelines to analyse their viability using conventional and alternative techno-economic assessment tools.

Typically, a techno-economic analysis (TEA) for industrial processes consists in the estimation of capital costs (CAPEX), operating costs (OPEX) and revenue based on technical and financial input parameters, namely cost/benefit analysis. The main uses are the evaluation of the economic feasibility of the process under a certain set of assumptions, the identification of research and development targets with the greatest potential to improve profitability and the quantification of uncertainty and potential risks.

Since IS solutions emerge from the need to valorise waste streams and avoid emissions or landfilling and imply the exchange of waste the energy and material streams from stakeholders, the sole analysis of CAPEX and OPEX of the new industrial processes does not suffice to assess their viability. Apart from these expenditures, the stakeholders should fully identify and quantify the cost of the waste streams that they are producing, i.e., which processes are generating a waste stream, and which would be the incurred costs in monetary units. For this purpose, a holistic analysis along the products lifecycle should be considered in order to quantify the monetary value of the waste disposal (transport, landfilling) or valorisation using the best available techniques. As such, there are several methods available for complementing the conventional TEA for industrial processes to assess IS solutions, examples being material flow cost accounting (MFCA), pinch analysis, exergy analysis, and life-cycle cost assessments (LCA).

Among them, MFCA resembles a promising tool for quantifying the flows and stocks of materials in processes or production lines in both physical and monetary units [1], revealing the hidden costs (such as system costs, waste management costs and other environmental costs) of production inefficiencies and losses, by putting in place an information system to track and monitor the non-product output costs as well as other environmental costs. In IS, the advantage of MFCA is that it provides an overview of how the input-output efficiency of a group of industries and how the utilization has been done. Furthermore, taking into account the technology to be applied one can estimate the inputs and outputs of the industry to be developed, and also estimate opportunity of implementation.

MFCA can be conducted in different ways and its implementation is dependent on the specific context of its use. Applied to IS, the "quantity centers" of a traditional MFCA, i.e. selected parts of a process where material and energy flows are stocked or transformed, can be referred to companies as a whole, as it is shown in Figure 1, or to sets of processes within an individual company, depending on the required level of detail.

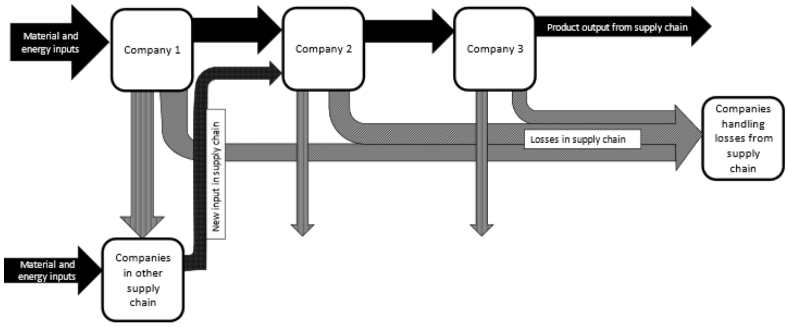


Figure 1. Integration of MFCA assessments between companies within a supply chain and between supply chains.

**Case studies**

In order to evaluate the suitability of MFCA as useful tool to conduct the techno-economic assessment of industrial symbiosis interactions, the methodology has been implemented for the evaluation of two real IS scenarios in demo sites under development. The first demo refers to a Spanish fertilizers company in which a process upgrade has been envisioned to drastically reduce the use of water and energy input, to avoid the generation of certain by-products and the recovery of raw materials by using an acid waste flow from a neighbouring industry. The second implies a prospective IS solution aiming at utilizing $CO_2$-rich flue gases and waste heat from a Swedish pulp & paper industry as feedstock and energy source, respectively, to establish a 10 ha greenhouse for tomato cultivation and a land-based shrimp farm in a neighbouring region. This approach could also be applied to other sectors not only exchanging gas or liquid streams but solid ones too.

**Results**

The application of MFCA coupled with cost/benefit analysis was a convenient methodology to tackle the techno-economic assessment of the specific IS scenario in the Spanish demo. Since the average mass and energy balances of both pre- and post-IS solution could be estimated and the main sources of waste flow could be identified, the static MFCA analysis procedure could proceed smoothly. The most difficult step was the allocation of costs for the waste flows and the overall pricing of mass and energy flows for a realistic assessment, given the current market price fluctuation for feedstocks, energy and fuels. Although this approach allows getting a first preliminary insight into the IS economics and viability, the static behaviour is not fully representative of the daily production basis. A more realistic and detailed MFCA (and OPEX evaluation) should consider the hidden costs coming from transient operations (start-up and shut-down periods derived from seasonal fertilizer production) and not envisioned waste generation.

In the Swedish case, the comprehensiveness and the use of a techno economic assessment is traditionally dependent on the maturity of the project, i.e., a tender is expected to be more accurate than an early techno-economic assessment. The Swedish case is a prospective symbiosis that is currently being built so most of the major investments are already done. The motivation for MFCA was to include improved resource efficiency as a parameter for the remaining decisions and thereby seeking both environmental and financial benefits simultaneously.

**Conclusions**

The complexity of the MFCA methodology depends on the degree of detail that the user requires regarding the waste streams characterization and price allocation. Nevertheless, the sole use of MFCA-based methodologies does not suffice to get the full picture on the IS scenario or to establish guidelines on price setting for the exchanged waste flows. For this purpose, a characterization of CAPEX and OPEX of the involved equipment for waste upgrading, as well as setting of boundary conditions for the traditional economic indicators (maximum payback period, minimum return of investment after certain time frame) are required to complement the MFCA. The MFCA coupled with a cost/benefit analysis has been applied to two real IS scenarios in demo sites under development and the outcome has established a price frame for the flows exchange, from a technical point of view only and has improved the resource efficiency not only form the financial point of view but also from the environmental one. Other factors such market price, margin of benefits and stakeholders negotiation would tune the so-called "technical" exchange price into the final IS deal.

**Acknowledgments**

This paper is supported by European Union's Horizon 2020 research and innovation programme under grant agreement No. 958337, project Coralis.

**References**

[1] ISO 14051:2011. Environmental management – Material flow cost accounting – General framework. Available at: www.sis.se (Accessed: 23 May 2022).