Circular Economy Systems Engineering for Food Supply Chains: A Case Study on the Coffee Supply Chain

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Food supply chains rely heavily on the extraction of finite natural resources, including phosphorus, potassium, and fossil fuels. Population growth, welfare growth, and the constant need for an increasing standard of living increase the demand for food, leading to natural resource degradation, increased landfill wastes, water contamination, and increased greenhouse gas emissions. Circular Economy (CE) can be a solution for the transition of food supply chains to a more sustainable and regenerative future [1]. To achieve such an economy model, we need to close loops and connect different stages of the food supply chains that in a linear economy are discrete. These interconnections along with the multiple stakeholders connected with them make decision making for CE food supply chains very challenging. A holistic systems engineering approach is thus clearly needed to navigate the multi-scale, multi-faceted, and interconnected CE food supply chain, identify opportunities for synergistic benefits and systematically explore interactions and trade-offs [2].

In this work, we present the foundations of a systems engineering framework and quantitative decision-making tools for the analysis and trade-off optimization of interconnected food supply chains. The framework combines data analytics and mixed-integer modeling & optimization methods to establish the interconnections between different stages of the circular food supply chains. The analysis of the trade-offs is empowered by the introduction of composite metrics for CE that include waste, energy, and resource use minimization, as means to facilitate decision making and compare alternative processes, materials, resources, and technological options.

To illustrate the applicability of the proposed framework we focus on the supply chain of coffee, as coffee is one of the most popular beverages worldwide with more than 155 million 60-kg bags of coffee being consumed yearly worldwide [3, 4]. The global coffee supply chain creates an estimated 23 million tons of organic coffee waste per year [5]. A superstructure representation of the supply chain of coffee is presented, which involves alternative pathways for coffee harvesting and processing, waste utilization, product distribution, and the introduction of new/alternative products. This analysis, in conjunction with feedback from experimentalists, led to the identification of the optimum CE supply chain for coffee.

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