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A hybrid life cycle optimization model for different microalgae cultivation systems

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Abstract

The environmental impacts analyses for the production of microalgal biomass include four key performance indicators: energy, water, carbon and land footprints. This work presents a life cycle optimization (LCO) model for microalgae production, taking into account these criteria for assessing different cultivation methods and carbon sources. The LCO model is formulated as a multiple objective linear program (MOLP), which is then solved to determine the Pareto optimal solutions. A hybrid approach is then developed where the analytic hierarchy process (AHP) is integrated for determining the weights of the environmental output criteria. This approach enables a unique optimum to be determined for the microalgae system.

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Keywords: Algal biomass; life cycle assessment; life cycle optimization, analytical hierarchy process

1. Introduction

Among biofuel feedstocks, algae stand as the most promising source for biofuel production based on its fast growth rate as well as fuel production equivalent per hectare and high yield [1]. Although biofuel is potentially CO_2 neutral the adverse environmental impacts of biomass production cannot be ignored. In

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the case of algal biomass, technologies for production need to be assessed based on environmental impacts such as energy, water, carbon and land footprints [2]. This paper presents a life cycle optimization (LCO) model for microalgae production, taking into account different cultivation methods and carbon sources. Two types of microalgae cultivation system, open pond and photobioreactor (PBR); and two different carbon sources, including starch and cellulose are used in this study.

2. Methodology

Life cycle assessment (LCA) is a quantitative tool for analyzing the impacts related to a product or process from the initial stage of raw material input to the end of life of the product [3]. Fig. 1 shows the overall system boundary for the biofuel production via microalgae cultivation. One ton of biofuel is defined as the functional unit. from the system consists of the following main steps: (a) microalgae cultivation process; (b) algae dewatering and (c) algae drying. The dried biomass algal is then preceded to lipid extraction and transesterification reactor for the biofuel production; however, the latter phase is excluded from the system boundary in this work.

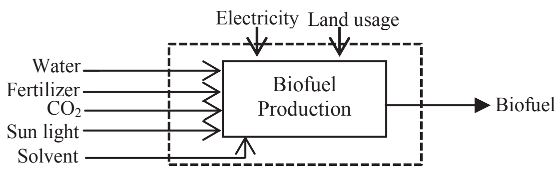

Fig. 1: Overall system boundary for biofuel from microalgae cultivation [4]

The environmental performance indicators can be further integrating into system optimization in order to assess the minimum impact of the system [5]. In generally, the approach for incorporating LCA into system optimization comprises of three main steps, which are: performing LCA study, then formulation of multi-objective optimization problem in the LCA context; and finally performing the multi-objective optimization and choose for the best compromise solution [6].

The life cycle optimization (LCO) model is formulated as a multiple objective linear program (MOLP), which is able to determine the Pareto optimal solutions (Fig. 2). A hybrid approach is developed where the analytic hierarchy process (AHP) is integrated for determining the weights of the environmental output criteria. The overall model is:

$$\text{minimize } \mathbf{f(x)} = \vec{\mathbf{w}}^{\mathbf{T}}(\vec{\mathbf{g}}^*)^{-1}\mathbf{g} \quad (1)$$

$$\mathbf{Ax} = \mathbf{y} \quad (2)$$

$$\mathbf{Bx} = \mathbf{g} \quad (3)$$

where **w** is the weight vector for the environmental impact indicator obtained using AHP approach, change of $(\vec{g}*)^{-1}$ serves to normalize impact scaling relative to the worst alternative. **A** is the technology matrix, **y** is the net output vector, and **x** is the gross output or scaling vector. Negative and positive values in each process column denote inputs and outputs, respectively. Eq. (1) indicates the overall material and energy balance for each of the processes, which can be scaled up or down by the scaling vector, **x**. Meanwhile, Eq. (2) exhibits the environment input to the process matrix, where **B** is the intervention matrix and **g** is the total value of the environmental footprint.