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A particle swarm approach for optimizing a multi-stage closed loop supply chain for the solar cell industry

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ABSTRACT

In order to implement sustainable strategies in a supply chain, enterprises should provide highly favorable and effective solutions for reducing carbon dioxide emissions, which brings out the issues of designing and managing a closed-loop supply chain (CLSC). This paper studies an integrated CLSC network design problem with cost and environmental concerns in the solar energy industry from sustainability perspectives. A multi-objective closed-loop supply chain design (MCSCD) model has been proposed, in consideration of many practical characteristics including flow conservation at each production/recycling unit of forward/reverse logistics (FL/RL), capacity expansion, and recycled components. A deterministic multi-objective mixed integer linear programming (MILP) model capturing the tradeoffs between the total cost and total CO_2 emissions was developed to address the multistage CSLC design problem. Subsequently, a multi-objective PSO (MOPSO) algorithm with crowding distance-based non-dominated sorting approach is developed to search the near-optimal solution of the MCSCD model. The computational study shows that the proposed MOPSO algorithm is suitable and effective for solving large-scale complicated CLSC structure than the conventional branch-and-bound optimization approach. Analysis results show that an enterprise needs to apply an adequate recycling strategy or energy saving technology to achieve a better economic effectiveness if the carbon emission regulation is applied. Consequently, the Pareto optimal solution obtained from MOPSO algorithm may give the superior suggestions of CLSC design, such as factory location options, capacity expansion, technology selection, purchasing, and order fulfillment decisions in practice.

1. Introduction

Because of global warming and ecocide, countries worldwide have established environmentally friendly laws, regulations, and agreements to limit natural resource consumption and environmental disasters. Moreover, consumers are developing greater awareness of the environmental and social implications of their daily consumption decisions and are therefore beginning to make purchasing decisions related to their environmental and ethical concerns [1]. Consequently, many enterprises have begun producing environmentally friendly products and recycling their end-of-life (EOL) products to eliminate or mitigate the environmental harm induced by the production and consumption of their goods. An enterprise with the low carbon emission supply chain is guaranteed to achieve corporate social responsibility and increase competitive advantages. In order to implement sustainable strategies in a supply chain, enterprises should provide highly favorable and effective solutions for reducing carbon dioxide (CO_2) emissions, which leads to the problems of designing and managing a closed-loop supply chain (CLSC) [2]. This paper reviews a CLSC involving the recycling, disassembling, repairing, and refurbishing of EOL products.

According to the definition of CLSCs [3], a CLSC management process involves the design, control, and operation of a system to maximize value creation over a product's life cycle by dynamically revamping the product's value in various types and volumes of returns over time. Operating procedures that entail adopting EOL recycling approaches provide a revolutionary method of supplying raw materials, reduce fabrication costs, and minimize resource consumption. In this scenario, forward and reverse logistics (FL/RL) must be considered simultaneously when designing a complete supply chain network. Özceylan and Paksoy [4] proposed a mixed-integer mathematical model for a CLSC network that includes FL/RL with multiple periods and parts. Pishvaee and Razmi [5] employed a fuzzy mathematical programming approach that was based on a product life-cycle assessment (LCA) method for

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Table 1
The summary of recent sustainable supply chain design references

Scholar (Year)	Supply Chain Structure	Methodology	Objective Function	Characteristics		
				Integrated Forward and Reverse Logistics	Capacity/Technology Investment	Environmental Concerns
Realff *et al.* (2004) [6]	Open-loop	Robust mixed-integer linear programming (RMIP)	Single- objective (gross profit of supply chain)			✓
Sheu *et al.* (2005) [9]	Closed-loop	Mixed-integer linear programming (MILP)	Multi- Objective (profit of forward logistic; profit of reverse logistic)	✓		
Lu and Bostel (2007) [10]	Closed-loop	MILP; Lagrangian	Single- objective (total cost)	✓		
Salema *et al.* (2007) [11]	Closed-loop	Stochastic mixed-integer programming (SMIP)	Single- objective (total cost)	✓		
Frota Neto *et al.* (2008) [12]	Closed-loop	Multi-objective programming (MOP); EDA	Multi- Objective (environmental impact; total cost)	✓		✓
Ramudhin *et al.* (2009) [13]	Open-loop	MILP	Multi- Objective (total cost; carbon emission)			✓
Piplani and Saraswat (2011) [14]	Closed-loop	RMIP	Single- objective (total cost of supply chain)	✓		
Pishvaee *et al.* (2011) [15]	Closed-loop	RMIP	Single- objective (total cost of supply chain)	✓		
Wang*et al.* (2011) [16]	Open-loop	MILP	Multi- objective (total cost; carbon emission)		✓	✓
Chaabane*et al.* (2012) [7]	Closed-loop	MILP	Multi- Objective (Total cost; carbon emission)	✓	✓	✓
Özceylan and Paksoy (2012) [4]	Closed-loop	MILP	Single- objective (total cost)	✓	✓	
This work	**Closed-loop**	**MILP RMIP**	**Multi- objective (total cost of supply chain; carbon emission)**	✓	✓	✓

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