



A hybrid Tabu Search approach for the design of a paper recycling network

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ABSTRACT

This paper addresses the design of a paper recycling network including external procurement, in-house recycling of paper, technology selection and selling or disposing of co-products. In contrast to the literature, we consider a combined continuous and discrete facility location problem solved by a hybrid Tabu Search approach to enhance candidate facility locations. We provide rules of thumb regarding the length of the tabu list and suggestions regarding runtime boundaries in cases where pre-evaluations are elaborate. The results based on a real-life application case show the potential savings of in-house paper recycling compared to the solely external procurement of recovered paper.

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1. Introduction

Due to the natural scarcity of raw materials and to cost pressure, sustainable operations are one of the main challenges in gaining competitive advantages. This potential competitive advantage is the reason why the recycling of, e.g., glass, paper and plastics has grown considerably. Because the paper industry is one of the most important industries in the recycling sector, we will use it as a representative example for the following investigation. The paper sector in Europe demonstrates significant achievements while following the goal of Europe as a ‘recycling economy’. According to the [Confederation of European Paper Industries \(2009a\)](#), the ambitious aim to reach a paper recycling rate of 66% by 2010, was already exceeded in 2008 (see [Fig. 1](#)).

[Fig. 2](#) shows that paper production not only requires wood pulp but also other types of pulp, non-fibrous materials and recovered paper (RCP). To counteract the risk of using wood pulp as the main input factor, companies diversified the risk of an unreliable supply by considering alternative materials during the recent decades. Using RCP has become increasingly important in CEPI (Confederation of European Paper Industries) countries (17 European Union members plus Norway and Switzerland) in recent years. In 1992, only 35% of the input factors could be traced back to RCP, whereas in 2009, RCP amounted to 44.2%. The European paper industry is faced with new challenges arising from the rapid economic development of the Asian countries (e.g., China and India). Currently the world’s biggest consumer of RCP with a global market share in paper manufacturing of over 40%, Asia is covering its internal demand using imports from Europe and North America ([Confederation of European Paper Industries, 2009b](#)). The result of this development is high competition for RCP and price volatility. RCP has experienced a non-negligible increase in prices in Europe during recent years. Between 2006 and 2011, the procurement costs of RCP in Europe increased by more than 75% and even doubled from 2009 to 2011 ([Eurostat, 2011](#)). Additionally, RCP requires approximately 65% less energy resources compared to the processing of virgin fiber, and it reduces water pollution by 35% and air pollution by 74%, according to the [Bureau of International Recycling \(2011\)](#).

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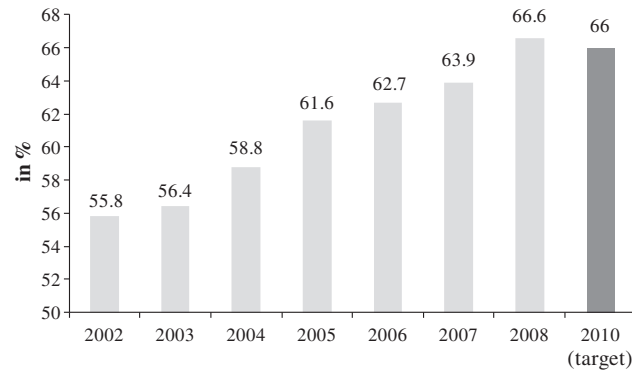


Fig. 1. Progress of the European paper recycling rate.

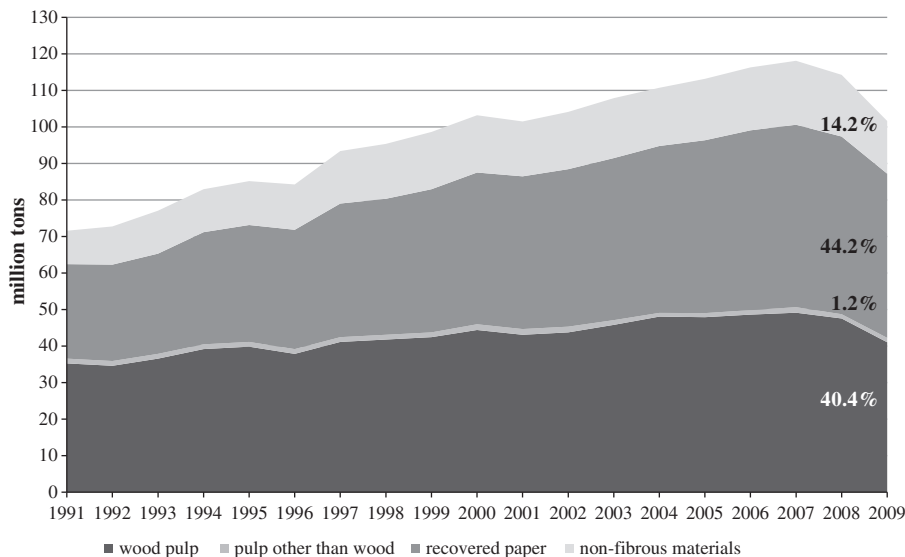


Fig. 2. Raw materials consumption in CEPI countries (Confederation of European Paper Industries, 2009b).

When analyzing the trends and the characteristics of RCP markets, the following aspects become obvious. Unsorted products and materials as post-consumer goods are highly heterogeneous due to their diverse geographical and physical origin, and they therefore differ in terms of quality and physical characteristics. This variation requires the appropriate pre-processing steps to transform the used products into re-usable products (i.e., sorting, additional production processes, etc.). The consumption of paper products strongly correlates with the overall economic situation (e.g., expenditure on advertising) and hence has a direct impact on the amount of RCP available on the market. The resulting uncertainties in supply demonstrate the main difference between reverse supply chains compared to traditional ones, where demand, apart from lead times, is an important stochastic influencing factor.

The following is a summary of the presented problem: The design of a paper recycling network is an essential task for paper manufacturing companies to satisfy the company's demand for RCP and to reduce risks with regard to price volatility and the quality and availability of RCP.

After a review of the related literature on the design of reverse and closed-loop supply chain networks in Section 2, we provide a problem description as well as the mathematical model formulation in Section 3. We then present a hybrid Tabu Search approach in Section 4. Section 5 demonstrates the applicability of the presented solution approach by means of an application case based on a European paper manufacturing company. Finally, Section 6 discusses the results, and Section 7 concludes the paper and addresses the open questions for further research.

2. Related literature

Two planning problems divide the literature on reverse logistics with regard to the integration of the reverse network into the forward network: closed-loop and recovery networks. Closed-loop networks consider both forward and reverse flows

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