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## 《产业生态学报》

2004年冬, 第8卷第3期, 19-32页

## 题目: 克服生命周期评价(LCA)局限的三种对策

作者: Helias A. Udo de Haes, Reinout Heijungs, Sangwon Suh, Gjalt Huppes

关键字: 混和分析, 投入产出生命周期评价(IO-LCA), 生命周期评价(LCA), 方法论, 建模, 工具箱

**摘要:** 为扩大生命周期评价的时空精度和应用范围, 人们开展了很多生命周期评价的扩展研究, 以丰富产业生态学的科学内涵。但从应用的角度看, 另一些研究方法能够帮助获取更详细、更丰富的生命周期影响的信息。本文就此提出三种不同的对策: (1) 利用一个统一的模型——扩展生命周期评价; (2) 使用工具箱——使用不同的模型; (3) 运用混合分析——利用数据输入输出集成不同的模型。

LCA 正向着具有更大的时空精度和更广泛社会因素包容性的方向发展, 它的扩展应提供最大相容的解决方法。但发明一个包含大量数据和巨大投入的超级工具具有很大的风险。何况很多社会因素尚不能用功能单元来模拟。

开发一个工具箱为纳入各种时空信息和其他环境影响提供最大的灵活性。每一方面的工作都可通过相应的工具箱来完成, LCA 的刚性结构不再成为限制。但由此所得的结果往往缺乏兼容性, 不利于进一步综合。

为此, 我们提出第三种对策——混合分析。它比扩展 LCA 更灵活, 比 LCA 工具箱更兼容, 有望集两者之所长于一身, 提供一条比已知各种过程 LCA 和投入产出 LCA 组合更加有效的分析方法。本文通过几个实例来说明混合分析法的巨大潜力。

工具箱和混合分析方法的不断发展有望与 LCA 完全兼容起来, 从而成为第一种方法——扩展 LCA 的组成部分。

## Journal of Industrial Ecology

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## Three Strategies to Overcome the Limitations of Life-Cycle Assessment

Helias A. Udo de Haes, Reinout Heijungs, Sangwon Suh, and Gjalt Huppes

## KEYWORDS:

hybrid analysis, input-output life-style assessment (IO-LCA), life-cycle assessment (LCA), methodology, modeling, toolbox

## SUMMARY:

Many research efforts aim at an extension of life-cycle assessment (LCA) in order to increase its spatial or temporal detail or to enlarge its scope. This is an important contribution to industrial ecology as a scientific discipline, but from the application viewpoint other options are available to obtain more detailed information, or to obtain information over a broader range of impacts in a life-cycle perspective. This article discusses three different strategies to reach these aims: (1) extension of LCA—one consistent model; (2) use of a toolbox—separate models used in combination; and (3) hybrid analysis—combination of models with data flows between them.

Extension of LCA offers the most consistent solution. Developments in LCA are moving toward greater spatial detail and temporal resolution and, the inclusion of social issues. Creating a supertool with too many data and resource requirements is, however, a risk. Moreover, a number of social issues are not easily modeled in relation to a functional unit.

The development of a toolbox offers the most flexibility regarding spatial and temporal information and regarding the inclusion of other types of impacts. The rigid structure of LCA no longer sets limits; every aspect can be dealt with according to the logic of the relevant tool. The results lack consistency, however, preventing further formal integration.

The third strategy, hybrid analysis, takes up an intermediate position between the other two. This strategy is more flexible than extension of LCA and more consistent than a toolbox. Hybrid analysis thus has the potential to combine the strong points of the other two strategies. It offers an interesting path for further discovery, broader than the already well-known combination of process-LCA and input-output-LCA. We present a number of examples of hybrid analysis to illustrate the potentials of this strategy.

Developments in the field of a toolbox or of hybrid analysis may become fully consistent with LCA, and then in fact become part of the first solution, extension of LCA.

## 《产业生态学报》

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**题目:** 一个关于可持续废物管理的决策支持框架**作者:** Robert Kijak, David Moy**关键字:** 废物综合管理(IWM), 生命周期评价(LCA), 生命周期评价解释, 多属性效用理论(MAUT), 全国污染物排放清单(NPI), 可持续性**摘要:** 本文介绍了一个用于评价地方行政区域(LGA)内城市固体废物综合管理情景的决策支持系统框架。

此研究旨在平衡废物的全球和区域环境影响、社区社会影响及经济影响以实现可持续的废物管理。该方法最初为澳大利亚昆士兰州的地方政府(如市议会)所开发, 但随后推广应用至其它地方。该决策支持框架包含了生命周期评价和其它环境、社会和经济分析工具。其中社会和经济方面的影响对发达国家而言十分近似。研究还对 LCA 过程中的清单分析和影响评价作了一定程度的简化。

为分析地方与区域层面上的不同影响, LCA 引入空间分辨。也就是在社区层面上考虑废物的社会影响, 在区域层面上则对 LCA 环境排放数据进行处理。

综合决策过程符合经合组织(OECD)提出的压力-状态-响应(PSR)模型方法, 并进一步包括了非环境因素, 以实现多种工具的集成应用。

此评价框架重点放在决策分析和解释过程。多属性效用理论(MAUT)用于帮助集成定性和定量的信息, 是一个进行信息评价、进行客观而透明决策的工具。本文所述的决策框架就是建立在一个 MAUT 决策分析的商业软件平台之上。

## Journal of Industrial Ecology

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**A Decision Support Framework for Sustainable Waste Management**

Robert Kijak and David Moy

**KEYWORDS:**

integrated waste management (IWM), life-cycle assessment (LCA), life-cycle assessment interpretation, multiattribute utility theory (MAUT), National Pollutant Inventory (NPI), sustainability

**SUMMARY:**

This article describes a decision support framework for the evaluation of scenarios for the integrated management of municipal solid waste within a local government area (LGA).

The work is initially focused on local government (i.e., municipal councils) in the state of Queensland, Australia; however, it is broadly applicable to LGAs anywhere. The goal is to achieve sustainable waste management practices by balancing global and regional environmental impacts, social impacts at the local community level, and economic impacts. The framework integrates life-cycle assessment (LCA) with other environmental, social, and economic tools. For this study, social and economic impacts are assumed to be similar across developed countries of the world. LCA was streamlined at both the life-cycle inventory and life-cycle impact assessment stages.

For this process, spatial resolution is introduced into the LCA process to account for impacts occurring at the local and regional levels. This has been done by considering social impacts on the local community and by use of a regional scaling procedure for LCA data for emissions to the environment that may have impacts at the regional level.

The integration follows the structured approach of the pressure-state-response (PSR) model suggested by the Organisation for Economic Cooperation and Development (OECD). This PSR model has been extended to encompass nonenvironmental issues and to guide the process of applying multiple tools.

The framework primarily focuses on decision analysis and interpretation processes. Multiattribute utility theory (MAUT) is used to assist with the integration of qualitative and quantitative information. MAUT provides a well-structured approach to information assessment and facilitates objective, transparent decisions. A commercially available decision analysis software package based on MAUT has been used as the platform for the framework developed in this study.

## 《产业生态学报》

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题目: 食品环境系统的污水处理分析: 一种包含富营养化影响的方法

作者: Ulf Sonesson, Håkan Jönsson, Berit Mattsson

关键字: COD, 环境, 生命周期评价(LCA), 材料流分析(MFA), 营养流, 污水系统

摘要: 食品通常含有较高的营养成分, 它们经过人体组织吸收后进入污水系统。关于污水系统的研究显示污水系统排放口处含有大量植物营养物。但污水中的这些高营养成分却很少为食品和食品生产的环境系统分析所考虑在内, 因此一些重要的环境影响可能被忽略。

本文介绍了如何在食品环境系统分析中包括食品消费后的污染排放, 并通过一些易于获取的数据计算了一些食品的消费后排放量。

本文利用 7 种食品的生命周期评价结果分析了其在一个污水处理厂排放口处对富营养化的影响。研究结果显示食品消费后的富营养化影响不容忽视, 其在食品生命周期总环境影响中所占的比重从 5.5%(牛肉)到 86%(苹果)不等。

在确定产品生命周期的最大环境影响以及开展产品生态标志认证时, 引入食品消费后排放都十分重要。当所研究的决策影响到食品消费后阶段时, 消费后过程应加以考虑。比较不同食品时, 如它们的营养成分不同, 消费后排放也应予以重视。

## Journal of Industrial Ecology

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### Postconsumption Sewage Treatment in Environmental Systems Analysis of Foods: A Method for Including Potential Eutrophication

Ulf Sonesson, Håkan Jönsson, and Berit Mattsson

#### KEYWORDS:

chemical oxygen demand (COD), environment, life-cycle assessment (LCA), materials flow analysis (MFA), nutrient flows, sewage systems

#### SUMMARY:

Food in general has a high nutrient content, which essentially passes through the human organism and ends up in the sewage system. This high nutrient content in sewage, however, is rarely included in environmental systems analyses of food products or production systems. At the same time, several studies on sewage systems have shown the significance of plant nutrients in sewage system outlets. This means that important environmental effects may be neglected in environmental systems studies of food.

We present a method for including emissions that occur after food consumption in environmental systems analyses of foods. The method uses easily accessible input data to calculate the postconsumption emissions caused by certain food products.

The method was tested by completing the results for eutrophication from seven life-cycle assessments (LCAs) on food products with the corresponding emissions caused by outlets from a sewage plant. The results showed that postconsumption eutrophication was a significant part of the products' total life-cycle impact, ranging from 5.5% (beef) to 86% (apples).

The conclusion is that including postconsumption emissions is important for studies aiming at mapping a product's life cycle to find the most environmentally relevant parts, as well as for eco-labeling purposes. If the purpose of the study is decision support, the postconsumption phase should be included where the decision affects this part of the system, otherwise not. When products are compared, postconsumption emissions should be included if their nutrient contents differ.

## 《产业生态学报》

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题目: 木材生产与消费长期协调性的动态物流能流分析

作者: Daniel B. Müller, Hans-Peter Bader, Peter Baccini

关键字: 动态模型, 林产品工业, 供应链管理, 材料流分析 (MFA), 资源效率, 制造年代效应

**摘要:** 本文采用一个木材和能流的动态模型分析了区域性木材管理。模型有机地结合了木材产业模块、林产品使用模块、废物管理模块、能量供应模块和一个与产地质量相关的森林生长模块, 并用 1900 至 1997 年间瑞士低地区域的数据作了校正。另外, 为探讨未来国产木材的作用, 还开发了直至 2100 年的可能情景。

模拟结果显示由于包括 20 世纪后半叶产地质量改善因素在内的种种原因, 现阶段木材过剩的趋势在 21 世纪将进一步增强。20 世纪中, 研究区域内的建筑面积增加了 5 倍, 而木材的建筑使用强度则下降了 4.5 倍, 从  $90 \text{ kg/m}^2$  降至  $20 \text{ kg/m}^2$ 。增加建筑使用木材的强度有可能减少木材过量生产的问题, 但建筑用材并不仅仅来自于国产木材。在一个特定的发展情景中, 现有建筑在 21 世纪将逐渐被以屋顶太阳能板和冬季采暖完全使用本地木材的新型建筑所替代, 目前水平上的木材生产和消费仍可望保持平衡。这些替代型建筑的建材使用强度与 20 世纪后期的建筑相似, 但能耗指标却低得多, 不到  $130 \text{ MJ/m}^2/\text{yr}$ 。

## Journal of Industrial Ecology

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**Long-term Coordination of Timber Production and Consumption Using a Dynamic Material and Energy Flow Analysis**

Daniel B. Müller, Hans-Peter Bader, and Peter Baccini

**KEYWORDS:**

dynamic modeling, forest products industry, integrated chain management, material flow analysis (MFA), resource efficiency, vintage effects

**SUMMARY:**

A dynamic model for wood and energy flows is used to analyze regional timber management. The model combines a site quality-dependent forest-growth module with modules for the timber industry, timber products use, waste management, and energy supply. The model is calibrated with data of a Swiss lowland region for the period of 1900-1997. Scenarios are developed for the period until 2100 in order to discuss possible future roles of domestic timber.

Model simulations show that, with present strategies, timber overproduction will further increase in the twenty-first century because of an increase in forest site quality in the second half of the twentieth century, among other reasons. The increase in building gross floor area of the region by a factor of 5 during the twentieth century coincides with a reduction of timber use in building construction by a factor of 4.5, from  $90 \text{ kg/m}^2$  to  $20 \text{ kg/m}^2$ . Increasing timber density in buildings could address overproduction; however, a strategy of timber construction could not be accomplished with domestic timber alone. A balance of production and consumption on the present level could also be achieved in a scenario in which the present building stock is gradually exchanged during the twenty-first century with buildings that use solar panels on roofs and domestic firewood as heat-energy sources exclusively. These replacement buildings would have density typical of late twentieth-century buildings, and they would need to perform on a low-energy standard of not more than  $130 \text{ MJ/m}^2/\text{yr}$ .

## 《产业生态学报》

2004 年冬, 第 8 卷第 3 期, 89-102 页

题目: 污染物摄入指数之地点依赖性的多介质模型分析: 北美四种污染物的案例研究

作者: Matthew MacLeod, Deborah H. Bennett, Merike Perem, Randy L. Maddalena, Thomas E. McKone, Don Mackay

关键字: 相对影响评价, 饮食接触途径, 接触, 健康影响, 多介质建模, 地点依赖

**摘要:** 产业生态学的重要特征之一, 即通过过程设计使对维持生命 (包括人类生命的) 的自然生态系统的干扰最小化。人类在人造污染物环境中的接触强度是一个十分复杂的函数, 与化学品排放量、化学品物化特性和活性以及环境特性和接触途径 (如呼吸、皮肤接触、饮食摄入) 等因素相关。一些化学品的释放点邻近高人口密度或食品生产区, 这也可能成为决定性影响因素。本文利用区域性 Berkeley-Trent (BETR) 北美有毒污染物跟踪模型和有关北美食品生产过程和人口密度的数据, 分析了不同影响因素的相对重要性。该模型用于分析四种释放到空气中的污染物, 包括苯、四氯化碳、苯并[a]芘和 2,3,7,8-四氯二苯并对二恶英。北美洲的总摄入指数 (iF) ——即人类接触量占毒物释放量之比例——被用来评价人类对这些有毒污染物的接触强度, 这可通过计算不同地区的污染物排放量得到。研究结果表明根据人口密度和食品生产的洲际平均值可对 iF 的中间值进行较准确的估算, 但 iF 值 (特别是通过食品摄入的化学品的 iF 值) 在此中间值两侧的分布范围可大到 3 个数量级。此外, 当利用生命周期评价来分析化学品排放对人类健康的影响时, 人口和食品生产相对于这些化学品来源地也是必须考虑的重要参数。

## Journal of Industrial Ecology

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### Dependence of Intake Fraction on Release Location in a Multimedia Framework: A Case Study of Four Contaminants in North America

Matthew MacLeod, Deborah H. Bennett, Merike Perem, Randy L. Maddalena, Thomas E. McKone, and Don Mackay

#### KEYWORDS:

comparative impact assessment, dietary exposure pathway, exposure, health effects, multimedia modeling, site dependency

#### SUMMARY:

A defining feature of industrial ecology is the design of processes to minimize any disruption of the functioning of the natural ecosystem that supports life, including human beings. The extent of human exposure to anthropogenic contaminants in the environment is a complex function of the amount of chemical emitted, its physicochemical properties and reactivity, the nature of the environment, and the characteristics of the pathways for human exposure, such as inhalation, dermal contacts, and intake of food and water. For some chemicals, the location of emissions relative to areas of high population density or intense food production may also be an important factor. We explore the relative importance of these variables using the regionally segmented Berkeley-Trent (BETR) North America contaminant fate model and data for food production patterns and population density for North America. The model is applied to four contaminants emitted to air: benzene, carbon tetrachloride, benzo[a]pyrene, and 2,3,7,8-tetrachlorodibenzo-p-dioxin. The total continental intake fraction (iF), relating exposure quantity to emission quantity, is employed as a metric for assessing population exposure to these contaminants. Results show that the use of continentally averaged parameters for population density and food production provides an accurate estimate of the median of iF calculated for emissions in individual regions; however, iF can range from this median by up to 3 orders of magnitude, especially for chemicals transferred to humans through foods. The locations of population and food production relative to sources of chemicals are important variables that should be considered when assessing the possible human health impacts of chemical emissions as in life-cycle assessment.

## 《产业生态学报》

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**题目: 以磷为例研究中国的物质流和生态重建****作者: Yi Liu, Arthur P. J. Mol, Jining Chen****关键字:** 生物地球化学, 生态重建, 富营养化, 化肥, 营养物, 物质流分析(SFA)

**摘要:** 环境问题与人类社会经济系统对材料的处理密切相关。传统的环境或经济分析方法很难深入了解经济系统的物质特性, 为此本文提出了一种结合物质流分析(SFA)和生态重建的综合分析方法, 用来分析正处在快速工业化过程中的中国的磷元素流, 以便更好地认识中国的材料使用及其随时间变化的趋势。本文依据 1996 年的统计数据建立了一个静态 SFA 模型, 跟踪确定了在国家经济中磷元素自来源至归宿的流动途径, 并确定了与磷元素流相关的环境影响。随后, 本文通过一套生态重建指标(ERIs), 动态分析了在过去 20 年间中国磷元素体系的结构变化和相关的生态重建过程。文章最后讨论了以国家磷元素流系统生态化(即减少磷元素流的生态影响)为目标的一些可能和希望的变化趋势。该方法对于了解经济系统的物质特性具有较高的应用价值。

## Journal of Industrial Ecology

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**Material Flow and Ecological Restructuring in China:  
The Case of Phosphorus**

Yi Liu, Arthur P. J. Mol, and Jining Chen

**KEYWORDS:**

biogeochemistry, ecological restructuring, eutrophication, fertilizer, nutrients, substance flow analysis

**SUMMARY:**

Environmental problems are closely related to society's processing of materials through the entire economy. Because neither traditional environmental nor economic analytical methods can provide sufficient insight into the physical dimension of economies, this article presents an integrated methodology, combining a substance flow analysis (SFA) approach and an ecological restructuring analysis. This approach is applied to phosphorus (P) in China, one of the most rapidly growing industrializing economies, in order to better understand of the economy's material use and its change over time. A static national SFA model is developed with statistical data from 1996. By tracking the national economy's P flows from origins to destinations, the critical P flows with respect to environmental impacts are identified. Based on the regime of national P flows, this article analyzes the degree of ecological restructuring by dynamically describing the structural changes of related critical P flows over the last two decades with a set of ecological restructuring indicators (ERIs). Finally, some potential and desired changes are discussed, with the goal of ecologizing the national P flow regime; that is, reducing the ecological impact of the national P flow regime. The methodology of this article illustrates its applicability and value for presenting an overall insight into the physical dimensions of national economies.

## 《产业生态学报》

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题目: 英格兰西北地区建筑材料流管理之物质平衡分析

作者: Darryn McEvoy, Joe Ravetz, John Handley

**关键字:** 混凝土砂石料, 材料流分析(MFA), 建材流, 区域方法, 资源管理, 可持续性

**摘要:** 本文建立了一个物质平衡模型, 来分析英格兰西北地区主要建筑材料的使用情况, 因为该地区进口的混凝土砂石料比英国其它任何一个地区都要多。建材与其它资源流的不同之处在于: 资源的污染和衰竭不是问题的主要方面; 而从开采、运输、加工到最终处置的物料生命周期各个阶段的环境影响是关注的重点。物质平衡模型可以促进人们对区域材料流和人类活动的生态影响的认识, 从而更好地开展有关决策。随着英国乃至欧盟对可持续资源管理和资源生产力的政治关注日趋加强, 开展这项研究十分有益。物质平衡模型分析了英格兰西北地区的建筑业和建筑材料流的环境可持续性影响: 该地区的建筑活动每年约消耗 34, 075TJ 的能量, 与能耗相关的二氧化碳排放量为 2, 701Gg, 与运输相关的二氧化碳排放量则为 387Gg。此外, 建材工业还为该地区提供了 147, 000 个就业岗位。

## Journal of Industrial Ecology

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**Managing the Flow of Construction Minerals in the North West Region of England: A Mass Balance Approach**

Darryn McEvoy, Joe Ravetz, and John Handley

**KEYWORDS:**

aggregates, materials flow analysis (MFA), mineral flows, regional approach, resource management, sustainability

**SUMMARY:**

This article, focusing on the flow of bulk construction minerals, establishes a mass balance framework for the North West of England, a region that imports more aggregate material than any other in the United Kingdom. The problems associated with construction minerals are of a different nature than most other resource flow issues: Depletion of resources and contamination are not considered major problems; rather it is the environmental impact resulting from life-cycle stages from extraction, transport, processing, through to final disposal that is most important. A mass balance framework can promote a better understanding of the regional flow of materials, and the impact of human activity on surrounding ecosystems, and hence underpin informed decision making. This is of particular relevance at the current time because increasing political emphasis is placed on sustainable resource management and resource productivity at the United Kingdom and European Union levels. Using a mass balance framework to analyze the sustainability impacts of construction and mineral flows in the North West of England, this study finds that flows resulting from construction activity account for 34,075 terajoules (TJ) of energy resulting in 2,701 gigagrams (Gg) of carbon dioxide emissions related to energy use, 387 Gg of carbon dioxide emissions related to the transportation of the minerals. Against these impacts, the flow of bulk construction minerals also supports 147,000 jobs within the region.



## 《产业生态学报》

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题目: 废纸回收与原生纸浆需求之间的非线性关系: 欧洲纸制品生产与回收的建模

作者: Niels J. Schenk, Henri C. Moll, José Potting

关键字: 节能, 二氧化碳排放, 纤维破坏, 焚烧, 最佳回收率, 灵敏度分析

摘要: 废纸可回收用于再生纸张或焚烧以回收能量。用于回收时, 再生纸浆可替代原生纸浆造纸。但由于废纸再生过程会破坏纸纤维, 因而纸张生产必须投入一定的原生浆, 所以废纸回收受到一定限制。由此可见废纸回收与资源需求之间的关系函数是一条曲线而非直线。本文通过一个数学模型来描述废纸回收率和原生纸浆需求之间的非线性关系。考虑能耗因素, 对化学制浆工艺而言废纸的最佳回收率是 93%, 机械制浆工艺则为 81%。灵敏度分析表明回收率较低时增大废纸的回收可显著提高能效, 而废纸回收率较高时这一改进则不明显。在接近最佳回收率时, 废纸回收率变化带来的能效变化幅度只有 0.3%。

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The Nonlinear Relationship between Paper Recycling and Primary Pulp Requirements: Modeling Paper Production and Recycling in Europe

Niels J. Schenk, Henri C. Moll, and José Potting

**KEYWORDS:**

energy savings, carbon dioxide emissions, fiber damage, incineration, optimum recycling rate, sensitivity analysis

**SUMMARY:**

Waste paper is suitable for recycling back into paper or for incineration for energy recovery. If waste paper is used for recycling, secondary pulp replaces virgin pulp. Fiber recycling is limited, however, because of physical constraints—particularly the breakage of fiber in the recycling process—and a permanent input of virgin fiber to the system is required. Therefore one can expect that the relationship between recycling rates and resource requirements is represented by a curved line rather than a straight one. In this article, we present a mathematical model that confirms that the relationship between recycling rates and primary pulp requirements can be described as nonlinear. Furthermore, we show that this nonlinear relationship leads to an optimal recycling rate with regard to energy consumption: 93% for paper produced from chemical pulp, and 81% for paper produced from mechanical pulp. Sensitivity testing additionally reveals that at low recycling rates increasing waste paper recycling is energy efficient, but it becomes less efficient at higher recycling rates. Close to the optimum recycling rates (within 10%), increasing or decreasing the rate affects the total energy requirement less than 0.3%.