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**中文摘要**  
**《产业生态学报》**  
**第23卷第5期**

**翻译**

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## 《产业生态学报》

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## 人类世的基础设施和环境

作者: Mikhail V. Chester, Samuel Markolf, Braden Allenby

关键字: 适应、人类世、复杂性、环境、基础设施、锁定

## 摘要:

历史上, 人工基础设施一直被视为与自然系统分离。然而在过去的几个世纪中, 随着人类活动的规模和范围急剧增加, 越来越多的证据表明自然系统正在变得越来越多, 在某些情况下甚至完全由人类来管理。基础设施与环境之间的分类逐渐变得模糊, 自然系统正日益成为人类的设计空间。显而易见人类对城市供水的水文系统、野生动植物、农业、森林、甚至大气层进行了管理。我们可以猜测, 随着人类活动的增长, 对环境的管理也将越来越多。但是, 我们的基础设施大多处于僵化状态。尽管环境和技术在加速变化, 基础设施却被设计为可以长期使用。因此, 面对人类世地球标志性的复杂集成系统和行为, 我们当前的基础设施范式失效了。未来的基础设施需要考虑适应能力和技术环境系统相关的复杂性进行设计。

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## Infrastructure and the environment in the Anthropocene

Mikhail V. Chester, Samuel Markolf, Braden Allenby

**Keywords:** adaptation, anthropocene, complexity, environment, infrastructure, lock-in**Summary:**

For centuries, man-made infrastructure has been viewed as separate from natural systems. Yet in the past few centuries, as the scale and scope of human activities have dramatically increased, there is accumulating evidence that natural systems are becoming increasingly, and in some cases entirely, managed by humans. The dichotomy between infrastructure and the environment is narrowing, and natural systems are increasingly becoming human design spaces. This is already apparent with the management of hydrologic systems for urban water supply, wildlife, agriculture, forests, and even the atmosphere, and we can expect management of the environment to become more so as human activities grow. Yet our infrastructure largely remains obdurate. They are designed to last for long times even as changes in the environment and technology accelerate. As such, our current infrastructure paradigms fail at the level of the complex, integrated systems and behaviors that characterize the Anthropogenic Earth. Infrastructure in the future will need to be designed for adaptive capacity and the complexities associated with techno-environmental systems.

## 《产业生态学报》

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## 社会经济代谢的通用数据模型及其在产业生态学数据共享原型中的应用

作者: Stefan Pauliuk, Niko Heeren, Mohammad Mahadi Hasan, Daniel B. Müller

关键字: 数据库, 数据模型, 产业生态学, 在线分析处理多维数据集, 开放科学, 社会经济代谢

## 摘要:

直到今天, 人们普遍认为产业生态学 (IE) 数据已存在于特定方法或模型的范围, 例如投入产出分析、生命周期评价、城市代谢或物质流分析数据。将工业系统或社会经济代谢中的对象和过程数据人为地划分为方法与这些数据所描述的普遍现象相矛盾。跨方法分散地组织相关数据的结果是, IE 研究人员和顾问花费太多时间来搜索和重新格式化来自各种来源的数据, 而这些时间本可以用于质量控制和模型结果分析。本文概述了一种解决方案, 针对以下两个 IE 中数据交换的主要障碍, 一是缺少 IE 数据的通用结构, 二是缺乏定制的平台来交换 IE 数据集。于是我们为 SEM (socioeconomic metabolism) 提供了一个通用数据模型, 该模型可用于构建位于工业系统中的所有数据, 包括过程描述、产品描述、存量、流量和各种系数。我们描述了一个基于通用数据模型的关系数据库及其用户界面, 它们都是开源的, 可以由单个研究人员、团体、机构或整个社区来操作。在后一种情况下, 可以说是 IE 数据共享 (IEDC), 我们将发布一个 IEDC 原型, 其中包含来自文献的各种数据集。

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## A general data model for socioeconomic metabolism and its implementation in an industrial ecology data commons prototype

Stefan Pauliuk, Niko Heeren, Mohammad Mahadi Hasan, Daniel B. Müller

Keywords: database, data model, industrial ecology, OLAP cube, open science, socioeconomic metabolism

## Summary:

Until this day, data in industrial ecology (IE) have been commonly seen as existing within the domain of particular methods or models, such as input-output, life cycle assessment, urban metabolism, or material flow analysis data. This artificial division of data into methods contradicts the common phenomena described by those data: the objects and processes in the industrial system, or socioeconomic metabolism (SEM). A consequence of this scattered organization of related data across methods is that IE researchers and consultants spend too much time searching for and reformatting data from diverse and incoherent sources, time that could be invested into quality control and analysis of model results instead. This article outlines a solution to two major barriers to data exchange within IE: (a) the lack of a generic structure for IE data and (b) the lack of a bespoke platform to exchange IE datasets. We present a general data model for SEM that can be used to structure all data that can be located in the industrial system, including process descriptions, product descriptions, stocks, flows, and coefficients of all kind. We describe a relational database built on the general data model and a user interface to it, both of which are open source and can be implemented by individual researchers, groups, institutions, or the entire community. In the latter case, one could speak of an IE data commons (IEDC), and we unveil an IEDC prototype containing a diverse set of datasets from the literature.

## 《产业生态学报》

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## 陆路出行的噪声足迹

作者: Stefano Cucurachi, Samuel Schiess, Andreas Froemelt, Stefanie Hellweg

关键字: 基于主体的建模、产业生态学、生命周期评估、噪音、私人出行需求、运输

## 摘要:

世界上很大一部分人口面临着不健康的噪声水平。然而, 在进行影响评估研究和设计政策干预措施时, 噪声常常被忽略。在这项研究中, 我们提供了一种方法来计算公民的噪声足迹, 这些噪声直接取决于他们在陆地上的私人 and 公共交通工具的使用。这项研究将应用于瑞士的大型运输模拟模型 MATSim 的结果与在生命周期评估的背景下开发的噪声特征模型 NLCA 结合在一起。MATSim 结果允许跟踪模型中主体的私人 and 公共交通使用。表征后的结果提供了基于消费的噪声足迹, 因此是由瑞士公民的私人出行需求引起的总噪声和影响。我们的结果证实, 道路运输是陆上交通的总噪声足迹的最大贡献方。我们还包括了向电动车全面过渡的情景, 该情景显示, 与使用内燃机车的模拟结果相比, 噪声影响可减少 55%, 尤其是在城市地区。

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## Noise footprint from personal land-based mobility

Stefano Cucurachi, Samuel Schiess, Andreas Froemelt, Stefanie Hellweg

**Keywords:** agent-based modeling, industrial ecology, life cycle assessment, noise, private mobility demand, transportation

**Summary:**

A large part of the world population is exposed to noise levels that are unhealthy. Yet noise is often neglected when impact assessment studies are conducted and when policy interventions are designed. In this study, we provide a way to calculate the noise footprint of citizens directly determined by their use of private and public transport on land. The study combines the results of the large transport simulation model MATSim applied to Switzerland, with a noise characterization model, N-LCA, developed in the context of life cycle assessment. MATSim results allow tracking the use of private and public transportation by agents in the model. The results after characterization provide a consumption-based noise footprint, thus the total noise and impacts that are caused by the private mobility demand of the citizens of Switzerland. Our results confirm that road transportation is the largest contributor to the total noise footprint of land-based mobility. We also included a scenario with a full transition to an electrified car fleet, which showed the potential for the reduction of impacts, particularly in urban areas, by about 55% as compared to the modeled regime with combustion engines.

## 《产业生态学报》

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## 制浆造纸厂生物污泥生产生物炭和能量回收的环境分析

作者: Ali Mohammadi, Maria Sandberg, G. Venkatesh, Samieh Eskandari, Tommy Dalgaard, Stephen Joseph, Karin Granström

关键字: 酸化、碳封存、林业、重金属、生命周期评价、土壤肥力

## 摘要:

瑞典是世界上最大的纸浆和纸制品出口国之一, 因此会产生大量富含碳质有机物及重金属的污泥。本文以填埋处理作为参照, 对可生产生物炭和从生物污泥中回收能量的三种技术进行了环境分析比较, 对焚化, 热解和水热碳化 (HTC) 三种热化学生物污泥管理系统使用生命周期评估 (LCA) 进行建模。假定焚烧过程 (系统 A) 中产生的热量作为牛皮纸浆厂内的自用热量, 由热解 (系统 B) 和 HTC (系统 C) 产生的生物炭 (焦炭和水炭) 添加到森林土壤中。LCA 结果表明, 相对于填埋处理, 所有替代系统都大大改善了生物污泥管理的环境效益。所有系统的温室气体排放量均净减少 (系统 A、B 和 C 中每吨干物质生物污泥的二氧化碳当量分别为 -0.89、-1.43 和 -1.13 吨)。系统 B 的潜在富营养化和陆地生态毒性影响最低, 而系统 C 的酸化潜力最小。分析结果表明, 从环境角度来看, 生物炭土壤改良剂作为处理纸浆和造纸厂生物污泥的替代方法, 比能量回收更具优势。但是, 最优生物炭系统也需要考虑社会和经济环境因素。

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## Environmental analysis of producing biochar and energy recovery from pulp and paper mill biosludge

Ali Mohammadi, Maria Sandberg, G. Venkatesh, Samieh Eskandari, Tommy Dalgaard, Stephen Joseph, Karin Granström

**Keywords:** acidification, carbon sequestration, forestry, heavy metals, life cycle assessment, soil fertility

## Summary:

Sweden is one of the largest exporters of pulp and paper products in the world. It follows that huge quantities of sludge rich in carbonaceous organic material and containing heavy metals are generated. This paper carried out a comparative environmental analysis of three different technologies, which can be adopted to produce biochar and recover energy from the biosludge, using landfilling as the reference case. These three thermochemical biosludge management systems—using incineration, pyrolysis, and hydrothermal carbonization (HTC)—were modeled using life cycle assessment (LCA). Heat generated in the incineration process (System A) was considered to be for captive consumption within the kraft pulp mills. It was assumed that the biochars—pyrochar and hydrochar—produced from pyrolysis (System B) and HTC (System C), respectively, were added to the forest soils. The LCA results show that all the alternative systems considerably improve the environmental performance of biosludge management, relative to landfilling. For all systems, there are net reductions in greenhouse gas emissions (-0.89, -1.43, and -1.13 tonnes CO<sub>2</sub>-equivalent per tonne dry matter biosludge in Systems A, B, and C, respectively). System B resulted in the lowest potential eutrophication and terrestrial ecotoxicity impacts, whereas System C had the least acidification potential. The results of this analysis show that, from an environmental point of view, biochar soil amendment as an alternative method for handling pulp and paper mill biosludge is preferable to energy recovery. However, an optimal biochar system needs to factor in the social and economic contexts as well.

## 《产业生态学报》

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## 制氢的工作条件: 社会生命周期评估

作者: Jasmin Werker, Christina Wulf, Petra Zapp

**关键字:** 替代燃料, 案例研究, 氢, 产业生态学, 生命周期思维, 社会生命周期评估

**摘要:**

新技术的社会影响可以与环境和经济后果并行地影响其可持续性。通过从生命周期的角度分析高级碱水电解(alkaline water electrolysis, AEL)的制氢案例, 本文说明了在德国、奥地利和西班牙安装电解器和制氢的社会影响。本文是对先前的环境和经济评估的补充, 后者根据电力生产的不同结构选择了这组被研究国家。本文使用混合方法设计来分析工艺流程链对工人的社会影响。根据《联合国 2030 年议程》可持续发展目标, 选择与工作条件有关的适当指标。选择对工人的关注作为测试相对较新的产品社会影响生命周期评估(Product Social Impact Life Cycle Assessment, PSILCA)数据库版本 2.0 的第一个示例。然后, 通过对基础原始数据的调查和定性文献分析, 对定量评估的结果进行补充和比较。总体而言, 高级 AEL 在德国流程链中对社会的影响最小, 其次是西班牙和奥地利。这三个流程链均显示对全局上游流程的影响。为了减少社会影响并最终为可持续发展做出贡献, 决策者和行业需要共同努力, 以进一步改善不同地区, 特别是全球上游流程中工作条件的某些方面。

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## Working conditions in hydrogen production: A social life cycle assessment

Jasmin Werker, Christina Wulf, Petra Zapp

**Keywords:** alternative fuels, case study, hydrogen, industrial ecology, life cycle thinking, social life cycle assessment

**Summary:**

Social impacts of novel technology can, parallel to environmental and economic consequences, influence its sustainability. By analyzing the case of hydrogen production by advanced alkaline water electrolysis (AEL) from a life cycle perspective, this paper illustrates the social implications of the manufacturing of the electrolyzer and hydrogen production when installed in Germany, Austria, and Spain. This paper complements previous environmental and economic assessments, which selected this set of countries based on their different structures in electricity production. The paper uses a mixed method design to analyze the social impact for the workers along the process chain. Appropriate indicators related to working conditions are selected on the basis of the UN Agenda 2030 Sustainable Development Goals. The focus on workers is chosen as a first example to test the relatively new Product Social Impact Life Cycle Assessment (PSILCA) database version 2.0. The results of the quantitative assessment are then complemented and compared through an investigation of the underlying raw data and a qualitative literature analysis. Overall, advanced AEL is found to have least social impact along the German process chain, followed by the Spanish and the Austrian. All three process chains show impacts on global upstream processes. In order to reduce social impact and ultimately contribute to Sustainable Development, policymakers and industry need to work together to further improve certain aspects of working conditions in different locations, particularly within global upstream processes.

## 《产业生态学报》

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### 在城市层面将生命周期评估与城市代谢相结合：西班牙城市间的比较

作者: [Sara González-García](#), [Ana Claudia Dias](#)

**关键字:** 毕尔巴鄂, 环境影响, 产业生态学, 塞维利亚, 可持续发展, 城市代谢

#### 摘要:

城市系统是重要的资源消费者和废物生产者, 这些废物源于其公民的生活方式和日常需求。量化由城市代谢 (UM) 引起的环境影响, 在设计更具可持续性的城市以及将决策策略转变为更有效的城市政策方面发挥着关键作用。本文将 UM 和生命周期评估方法相结合, 以量化城市范围内的物质和能量流以及衍生的城市环境压力, 从而优先考虑可持续性的环境方面。该方法论应用于西班牙毕尔巴鄂和塞维利亚这两个截然不同的城市。研究结果识别了建筑材料、电力、化石燃料以及食品和饮料的消耗是环境热点。结果主要受到气候差异 (极端条件) 的影响, 气候差异主要影响化石燃料的消费, 购买力差异则主要影响食物的摄入。进一步的研究应侧重于数据管理和质量, 以及设计更高效的城市以改善其环境状况 (例如通过引入更节能的建筑、可持续的建筑材料和公共交通)。

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### Integrating life cycle assessment and urban metabolism at city-level: Comparison between Spanish cities

[Sara González-García](#), [Ana Claudia Dias](#)

**Keywords:** Bilbao, environmental impacts, industrial ecology, Seville, sustainable development, urban metabolism

#### Summary:

Urban systems are important consumers of resources and producers of wastes derived from the lifestyles and daily needs of their citizens. The quantification of environmental impacts arising from urban metabolism (UM) plays a key role in the design of more sustainable cities and in the development of decision-making strategies into more effective urban policies. This article combines UM and lifecycle assessment methodology to quantify mass and energy flows within the city limits and derived urban environmental pressures, thus prioritizing the environmental perspective of sustainability. This methodology is applied to the two very different Spanish cities of Bilbao and Seville. The results acquired in this study identify the consumption of construction materials, electricity, fossil fuels, and food and beverages as environmental hotspots. The results are primarily affected by differences in the climate (extreme conditions), which mainly affect the consumption of fossil fuels, and differences in purchasing power, which mainly influence the intake of foodstuffs. Further research should focus on data management and quality as well as on designing more efficient cities (e.g., through the introduction of more energy-efficient buildings, sustainable building materials, and public transport) in order to create improvements in their environmental profiles.

## 《产业生态学报》

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## 循环水产养殖系统的生命周期评估: 以中国大西洋鲑鱼养殖为例

作者: Xingqiang Song, Ying Liu, Johan Berg Pettersen, Miguel Brandão, Xiaona Ma, Stian Røberg, Björn Frostell

**关键字:** 大西洋鲑鱼, 饲料生产, 室内水产养殖, 产业生态学, 生命周期评估 (LCA), 循环水产养殖系统

**摘要:**

循环水产养殖系统 (RAS) 是解决与常规网箱养殖系统相关的主要环境挑战的一项替代技术。为了系统地评估 RAS 的环境绩效, 需要考虑整个生命周期以避免临时的和次优的环境措施。生命周期评估 (LCA) 在水产养殖中, 尤其是在室内 RAS 中的应用至今仍在研究中。本研究报告了对中国北方一个室内 RAS 养殖场收获的大西洋鲑鱼的生命周期评估。结果表明, 生产 1 吨活重的鲑鱼需要 7509kWh 的农场级电力, 并产生 16.7 吨二氧化碳当量 (eq)、106 千克 SO<sub>2</sub>eq、2.4 千克 P<sub>eq</sub> 和 108 千克 N<sub>eq</sub> (从摇篮到农场门)。在评估的九种影响类别中, 有八种被认为是农场级用电量和饲料产品的主要贡献者 (总计 54 - 95%), 但潜在的海洋富营养化 (MEU) 影响除外 (以养殖废水为主)。在饲料成分中 (以干重计), 鸡肉粉 (5%) 主导了 9 种影响类别中的 6 种, 磷虾粉 (8%) 主导剩余 3 种影响类别。对于这个室内 RAS 养殖场, 本文建议的环境改善措施包括优化饲养密度、饲喂管理、污水处理、替代饲料原料以及选择发电来源。本研究有助于更好地了解陆生鲑鱼 RAS 作业的生命周期对环境的影响, 以及利益相关方之间就更环保的鲑鱼养殖进行科学交流。

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## Life cycle assessment of recirculating aquaculture systems: A case of Atlantic salmon farming in China

Xingqiang Song, Ying Liu, Johan Berg Pettersen, Miguel Brandão, Xiaona Ma, Stian Røberg, Björn Frostell

**Keywords:** atlantic salmon, feed production, indoor aquaculture, industrial ecology, life cycle assessment (LCA), recirculating aquaculture systems

**Summary:**

Recirculating aquaculture systems (RAS) are an alternative technology to tackle the major environmental challenges associated with conventional cage culture systems. In order to systematically assess the environmental performance of RAS farming, it is important to take the whole life cycle into account so as to avoid ad hoc and suboptimal environmental measures. So far, the application of life cycle assessment (LCA) in aquaculture, especially to indoor RAS, is still in progress. This study reports on an LCA of Atlantic salmon harvested at an indoor RAS farm in northern China. Results showed that 1 tonne live-weight salmon production required 7,509 kWh farm-level electricity and generated 16.7 tonnes of CO<sub>2</sub> equivalent (eq), 106 kg of SO<sub>2</sub> eq, 2.4 kg of P eq, and 108 kg of N eq (cradle-to-farm gate). In particular, farm-level electricity use and feed product were identified as primary contributors to eight of nine impact categories assessed (54–95% in total), except the potential marine eutrophication (MEU) impact (dominated by the grow-out effluents). Among feed ingredients (on a dry-weight basis), chicken meal (5%) and krill meal (8%) dominated six and three, respectively, of the nine impact categories. Suggested environmental improvement measures for this indoor RAS farm included optimization of stocking density, feeding management, grow-out effluent treatment, substitution of feed ingredients, and selection of electricity generation sources. In a generic context, this study can contribute to a better understanding of the life cycle environmental impacts of land-based salmon RAS operations, as well as science-based communication among stakeholders on more eco-friendly farmed salmon.



## 《产业生态学报》

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### 推动产业共生的工具：系统综述

作者: [Zhiquan Yeo](#), [Donato Masi](#), [Jonathan Sze Choong Low](#), [Yen Ting Ng](#), [Puay Siew Tan](#), [Stuart Barnes](#)

**关键字:** 循环经济, 产业生态学, 产业共生, 回收利用, 可持续性, 废物管理

#### 摘要:

产业共生 (IS) 运用跨组织的视角, 通过寻求资源和信息共享的企业间合作, 将一家公司的废物输出与另一家公司的投入进行协同配对。但是, 在公司之间协调 IS 关系仍然是一个复杂的过程。在文献中, 出现了各种各样的定性和定量工具, 解决了从识别 IS 的创建机会到绩效评估的问题。迄今为止, 现有文献集中于 IS 产生的不同方面和观点。每个单独的工作都在一定程度上促进了 IS 全过程的创建。文献提供的不同观点反映了可行的 IS 支持工具的碎片性质, 即这些工具彼此独立运行。迄今为止, 缺少支持 IS 创建过程工具的完整视图。因此, 为填补这一空白, 本研究旨在通过分析现有 IS 工具的相关方法、作用和贡献, 形成一种更全面的 IS 工具前景描述。通过这种理解, 所获得的见解可用于协助 IS 从业者工具的改进和研发。

## Journal of Industrial Ecology

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### Tools for promoting industrial symbiosis: A systematic review

[Zhiquan Yeo](#), [Donato Masi](#), [Jonathan Sze Choong Low](#), [Yen Ting Ng](#), [Puay Siew Tan](#), [Stuart Barnes](#)

**Keywords:** circular economy, industrial ecology, industrial symbiosis, recycling, sustainability, waste management

#### Summary:

Industrial symbiosis (IS) employs a cross-organizational perspective to seek synergistic pairings of one company's waste output to another company's input, enabled by interfirm cooperation through resource and information sharing. Orchestrating IS relationships among companies, however, remains a complex process. In the literature, a wide range of qualitative and quantitative tools have emerged, tackling issues ranging from identifying IS creation opportunities to performance evaluation. Thus far, the available literature has focused on separate aspects and perspective of IS creation. Each individual work contributes, in part, to the overall process of IS creation. The disparate perspectives provided by the literature reflect the fragmented nature of available tools supporting IS, which operate in isolation of each other. An encompassing view of tools supporting the process of IS creation is missing to date. Therefore, to fill this gap, this study aims to develop a more comprehensive description of the landscape of IS tools by analyzing the associated approaches, roles, and contribution of existing tools. Through this understanding, the insights gained can be used to aid future development and advancement of tools for IS practitioners.

## 《产业生态学报》

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<http://dx.doi.org/10.1111/jiec.12847>

## 各国二次锌储量评估

作者: Kyaw Nyunt Maung, Cherry Myo Lwin, Seiji Hashimoto

**关键字:** 产业生态学, McKelvey图, 回收, 二次资源, 存量核算, 城市采矿

**摘要:**

在解决金属的可持续利用问题时, 不仅要考虑自然环境中的初级金属, 还要考虑替代资源, 例如社会中发现的二次金属。为此目的, 阐明二次金属, 即二次金属储量的可用性是很重要的。采用次级资源分类框架来调查其对锌的适用性, 并评估主要目标国家的次级锌储量和资源。该研究结果估计, 日本和美国的二次锌储量分别为 0.14 亿吨和 0.13 亿吨, 并显示了研究国家的二次锌储量的估计总量相当于全球初级锌储量的 24%。按人均计算, 法国、德国和日本的二次锌储量最大。应用分类框架表明, 在填埋场中发现了相当数量的二次锌资源, 为二次锌填埋场的采矿提供了未来的潜在目标。该框架提供了有关次级锌资源的大小和位置的详细信息。这些信息对于行业和政策制定者都非常有用, 可以最大限度地获取有价值的二次锌资源。本研究还强调了对原锌和二次锌资源进行综合管理的必要性。

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## Assessment of secondary zinc reserves of nations

Kyaw Nyunt Maung, Cherry Myo Lwin, Seiji Hashimoto

**Keywords:** industrial ecology, McKelvey diagram, recycling, secondary resources, stock accounting, urban mining

**Summary:**

When addressing the sustainable use of metals, one must consider not only primary metals in the natural environment but also alternative resources, such as secondary metals found in society. For that purpose, elucidating the availability of secondary metals, that is, secondary metal reserves, is important. A classification framework of the secondary resources was applied to investigate its applicability to zinc and to assess the secondary zinc reserves and resources of major targeted countries. Our estimates show that Japan and the United States have secondary zinc reserves of 14 and 13 Mt, respectively, and showed the total estimated amount of secondary zinc reserves of the study countries is equivalent to about 24% of the global primary zinc reserves. On a per-capita basis, France, Germany, and Japan have the largest secondary zinc reserves. The application of a classification framework showed that a considerable amount of secondary zinc resources is found in landfills, providing a future potential target for secondary zinc landfill mining. The framework provides details about the sizes and locations of secondary zinc resources. This information is useful for both industry and policy makers to maximize access to valuable secondary zinc sources. This study also highlights the necessity for the integrated management of primary and secondary zinc resources.

## 《产业生态学报》

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## 利用具有空间分辨率的商品流数据和货运数据刻画城市的物质流动

作者: [Lih Wei Yeow, Lynette Cheah](#)

关键字: 大数据、地理信息系统、产业生态学、货车司机行为调查、城市代谢

## 摘要:

分析并提升城市地区的资源效率, 依赖于对城市代谢的刻画, 尤其是城市的物质流动, 这是因为物质流分析有助于把握城市的动态和物质的转变和转移。现有城市代谢研究一般聚焦于城市尺度的物质流分析, 其研究方法大多数衍生于欧盟统计局的物质流分析方法。换句话说, 这些研究本质上还是将城市视作“黑箱”, 未能揭示城市内部代谢的复杂过程。因此, 本文认为, 为理解城市内部的物质转移和扩散过程, 需要借助于对城市内部商品流动过程的分析; 对城市商品流动的细致刻画, 可以帮助了解城市的物质资源使用和资源效率的提升空间。本文针对美国的商品流动数据库和新加坡货车定位活动数据库展开了物质流分析, 其中, 新加坡货车定位活动数据库的收集过程借助了机器学习等大数据分析技术。基于此, 本文利用地理空间系统和空间可视化技术对物质的空间流动进行了细致的刻画, 揭示了城市空间内部物质的空间流动, 从而有助于打开“黑箱”, 探视城市内部的代谢机制与流动过程, 解释并理解城市内部人类活动及其对城市环境的影响。

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## Using spatially explicit commodity flow and truck activity data to map urban material flows

Lih Wei Yeow, Lynette Cheah

Keywords: big data, geographic information systems, industrial ecology, truck driver activity survey, urban metabolism

## Summary:

To analyze and promote resource efficiency in urban areas, it is important to characterize urban metabolism and particularly, material flows. Material flow analysis (MFA) offers a means to capture the dynamism of cities and their activities. Urban-scale MFAs have been conducted in many cities, usually employing variants of the Eurostat methodology. However, current methodologies generally reduce the study area into a “black box,” masking details of the complex processes within the city's metabolism. Therefore, besides the aggregated stocks and flows of materials, the movement of materials—often embedded in goods or commodities—should also be highlighted. Understanding the movement and dispersion of goods and commodities can allow for more detailed analysis of material flows. We highlight the potential benefits of using high-resolution urban commodity flows in the context of understanding material resource use and opportunities for conservation. Through the use of geographic information systems and visualizations, we analyze two spatially explicit datasets: (1) commodity flow data in the United States, and (2) Global Positioning System-based commercial vehicle (truck) driver activity data in Singapore. In the age of “big data,” we bring advancements in freight data collection to the field of urban metabolism, uncovering the secondary sourcing of materials that would otherwise have been masked in typical MFA studies. This brings us closer to a consumption-based, finer-resolution approach to MFA, which more effectively captures human activities and its impact on urban environments.

## 《产业生态学报》

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## 农业潜在净初级生产足迹: 全球贸易分析

作者: Jan Weinzettel, Dava Vačkářů, Helena Medková

**关键字:** 消费、足迹、人类对净初级生产力的占有率 (HANPP)、国际贸易、多区域投入产出分析 (MRIO)、净初级生产 (NPP)

**摘要:**

农业是人类社会最重要的生物质来源之一, 但是, 通过对生物多样性、生态系统完整性、气候变化和生态系统服务的消极影响, 越来越多地导致生态系统的人为退化。本研究从消费者责任的角度 (足迹) 估算了 NPP<sub>pot</sub> 的农业足迹, 即全球农田和人工牧场对潜在净初级生产 (NPP<sub>pot</sub>) 的占用水平, 进而揭示了国际贸易的作用。为了量化 NPP<sub>pot</sub> 的农业足迹, 我们利用环境拓展的多区域投入产出分析, 将全球农田和人工牧场改变的陆地潜在 NPP 归因于负责拉动供应链的最终消费者。我们确定了 236 个国家 186 种农业作物的地理特定农田面积的 NPP<sub>pot</sub>, 并通过国际贸易和供应链的全球网络跟踪每种作物, 直至最终消费。研究表明, 人类社会通过将自然生态系统转变为农田和人工草地, 占用了全球潜在净初级生产量的 20% (每年 13 千兆克碳)。国际贸易占全球农业 NPP<sub>pot</sub> 足迹的 23%, 而生活在中国和印度 (人均 NPP<sub>pot</sub> 农业足迹最低的两个国家) 的 25 亿人口约占全球农田和人工草地 NPP<sub>pot</sub> 农业足迹的 16%, 在人均足迹最高的国家, 仅仅 3.6 亿人占有同样的份额。

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## Potential net primary production footprint of agriculture: A global trade analysis

Jan Weinzettel, Dava Vačkářů, Helena Medková

**Keywords:** consumption, footprint, human appropriation of net primary productivity (HANPP), international trade, multi-regional input-output analysis (MRIO), net primary production (NPP)

**Summary:**

Agriculture is one of the most important sources of biomass for human society but increasingly contributes to anthropogenic degradation of ecosystems through negative impacts on biodiversity, ecosystem integrity, climate change, and ecosystem services. Here we estimate NPP<sub>pot</sub> agricultural footprint, that is, the level of appropriation of potential net primary production (NPP<sub>pot</sub>) by global cropland and human-made pastures from the consumer responsibility (footprint) perspective and reveal the role of international trade. To quantify the NPP<sub>pot</sub> agricultural footprint, we utilize environmentally extended multi-regional input-output analysis to attribute the terrestrial potential NPP altered by global cropland and human-made pastures to the final consumers responsible for pulling the supply chains. We identify the NPP<sub>pot</sub> of geographically specific cropland area of 186 agricultural crops in 236 countries and we track each of those crops through the global web of international trade and supply chains to the point of final consumption. We show that human society appropriates 20% (13 petagrams of carbon per year) of global potential net primary production by the transformation of natural ecosystems into cropland and human-made pastures. International trade accounts for 23% of global NPP<sub>pot</sub> footprint of agriculture. While the two and half billion people living in China and India (the two countries with lowest NPP<sub>pot</sub> agricultural footprint per capita) appropriate about 16% of the global NPP<sub>pot</sub> agricultural footprint of cropland and human-made pastures, the same share is appropriated by only 360 million people living in countries with the highest per capita footprint.

## 《产业生态学报》

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## 催化转化器中金属铂的闭环回用: 物质流分析和循环性指标的贡献

作者: Michael Saidani, Alissa Kendall, Bernard Yannou, Yann Leroy, François Cluzel

关键字: 催化转化, 循环经济, 循环性指标, 物质流分析, 铂, 价值链

## 摘要:

本研究利用物质流分析(MFA)方法对欧洲催化转化器(CC)中铂(Pt)的循环经济(CE)进行量化分析。首先, 将价值链和相关的利益相关者按照MFA的方法进行描述, 以便评估存量和流量, 并全面了解可能的作用机制和可回收的资源以实现资源闭环利用。然后, 通过对众多数据的交叉分析, 完成了两个层面MFA: (i) 一个通用MFA; (ii) 一个特定行业的MFA, 从而区分了(a) 轻型车辆的催化转化器Pt的去向以及(b) 重型车和越野车。研究表明, 2017年欧洲市场之外损失约15吨Pt。其中, 大约25%是由于催化转化器使用中的损耗造成的, 65%的损失是由于催化转化器使用以后回收不力和出口不受管制。通过比较初级生产和次级生产的环境影响, 结果表明, 在使用和回收过程中将Pt的损失量减半可以减少 $1.3 \times 10^3$  TJ的能量消耗和 $2.5 \times 10^2$  kt CO<sub>2-e</sub>的温室气体排放。根据循环性指标分析结果, 提出采用适当的激励机制以促进欧洲催化转化器中Pt循环经济性, 这对于将来生产的新一代催化转化器和燃料电池的循环经济至关重要。此外, 为了更好地回收正在使用的催化转化器中Pt的存量, 政府部门需要更好的回收机制。而且, 也不能忽略催化转化器使用过程中排放到环境中的Pt。最后, 由于数据的不可得以及数据的时效性问题, 希望有更多的关于催化转化器Pt回收的相关研究, 以及催化转化器使用对人类健康的影响。

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## Closing the loop on platinum from catalytic converters: Contributions from material flow analysis and circularity indicators

Michael Saidani, Alissa Kendall, Bernard Yannou, Yann Leroy, François Cluzel

Keywords: catalytic converter, circular economy, circularity indicators, material flow analysis (MFA), platinum, value chain

## Summary:

In this study, material flow analysis (MFA) is applied to quantify and reduce the obstacles for advancing a circular economy (CE) of platinum (Pt) from catalytic converters (CC) in Europe. First, the value chain and related stakeholders are mapped out in an MFA-like model to both facilitate the assessment of stocks and flows, and get a comprehensive view of potential action levers and resources to close-the-loop. Then, through the cross analysis of numerous data sources, two MFA are completed: (i) one general MFA, and (ii) one sector-specific MFA, drawing a distinction between the fate of Pt from (a) light-duty vehicles, under the European Union's End of Life Vehicle Directive 2000/EC/53, and (b) heavy-duty and off-road vehicles. Key findings reveal a leakage of around 15 tons of Pt outside the European market in 2017. Although approximately one quarter of the losses are due to in-use dissipation, 65% are attributed to insufficient collection and unregulated exports. Comparing the environmental impact between primary and secondary production, it has been estimated that halving the leakage of Pt during usage and collection could prevent the energetic consumption of  $1.3 \times 10^3$  TJ and the greenhouse gases emission of  $2.5 \times 10^2$  kt CO<sub>2</sub> eq. Through the lens of circularity indicators, activating appropriate action levers to enhance the CE performance of Pt in Europe is of utmost importance in order to secure future production of new generations of CC and fuel cells. Moreover, the growing stockpile of Pt from CC in use indicates the need for better collection mechanisms. Also, the CC attrition during use and associated Pt emissions in the environment appears non-negligible. Based on the scarce and dated publications in this regard, we encourage further research for a sound understanding of this phenomenon that can negatively impact human health.

## 《产业生态学报》

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## 用肉、谷类、豆类和乳制品代替从鱼中摄入饮食蛋白的全球经济成本

作者: Ignacio Cazcarro, Carlos A. López-Morales, Faye Duchin

关键字: 饮食与环境、产业生态学、投入产出分析、情景分析、世界贸易模型

## 摘要:

本文估算了用肉类、谷物豆类或乳制品中的蛋白质代替从鱼中摄入蛋白质的成本。我们应用世界贸易模型(一种基于比较优势的主要世界地区之间相互作用的投入-产出模型)来分析有关全球饮食中蛋白质含量和来源的替代情景。我们发现,用肉类或乳制品替代鱼每年需要增加数亿美元的额外费用,这与牧场,耕地,水和其他生产要素的使用增加有关。由于需要吸引成本较高的生产者进入贸易网,动物产品的价格急剧上涨以便向稀缺资源的所有者支付租金。相比之下,以谷物和豆类替代鱼类的全球经济变化成本较低,但是这种饮食转变涉及到农业产出及其地理分布的实质性变化。很少有分析性研究能够将成本和价格直接与特定饮食选择组合相关联。我们提供了灵活的经济框架,用于分析有关当前和未来食品生产的替代情景。专注于为人类饮食提供蛋白质,允许在陆基和水生资源之间进行替代,这为随后进一步研究水产养殖的潜在未来贡献奠定了基础,并且可以在一个更广泛的框架内研究下一代大坝对鱼类栖息地和淡水生态系统的影响。

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## The global economic costs of substituting dietary protein from fish with meat, grains and legumes, and dairy

Ignacio Cazcarro, Carlos A. López-Morales, Faye Duchin

Keywords: diet and environment, industrial ecology, input-output analysis (IOA), scenario analysis, world trade model

## Summary:

This paper estimates the costs to replace fish by protein from meat, from grains and legumes, or from dairy products. We apply the World Trade Model, an input-output model of the interactions among major world regions based on comparative advantage, to analyze alternative scenarios about protein content and sources in global diets. We find that the substitution of fish by meat or dairy entails several trillion U.S. dollars of additional costs annually, corresponding to increased use of pastureland, cropland, water, and other factors of production. The price of animal products increases steeply as higher-cost producers need to come online, yielding rents to owners of scarce resources. By contrast, the global economy adjusts at significantly lower costs to the substitution of fish by grains and legumes, but this dietary shift involves substantial modification in the mix of agricultural output and its geographic distribution. There have been few analytic studies able to associate costs and prices directly with specific combinations of dietary options. We provide a flexible economic framework for analyzing alternative scenarios about the present and future production of food. The focus on the provision of protein for the human diet, allowing for substitutions between land-based and aquatic sources, lays the groundwork for subsequent closer examinations of the potential future contribution of aquaculture and, in a yet broader framework, the impact of the coming generation of large dams on fish habitat and freshwater ecosystems more generally.

## 《产业生态学报》

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## 使用混合 LCA 多目标优化模型对德国木质纤维素生物精炼厂进行评估

作者: Maik Budzinski, Otávio Cavalett, Roy Nitzsche, Anders Hammer Strømman

关键字: 生物质, 混合生命周期评价, 产业生态学, 线性规划, 多目标

## 摘要:

本文提出了一种分层混合生命周期评价(LCA)多目标优化模型,并将其应用于确定德国新的生物精炼技术的最佳选择。因此,可以明确地解决多方面问题,包括在地区上对可持续原料的可用性进行区分、确定全球价值链上的环境影响识别以及确定不同可持续目标之间的取舍。该模型用于评估两个木质纤维素生物精炼概念之间的最佳选择,考虑两个优化目标:最大化投资者的利润和尽量减少特定产品需求对气候变化的影响。在环境影响方面,该模型还考虑了新生物精炼厂与产生特定最终需求的现有技术的比较。实例研究结果表明,包括乙烯生产在内的生物精炼厂在减少气候影响方面更为有利,而包括乙醇生产在内的生物精炼厂则更具有成本效益。根据决策者对这两个目标权重的偏好,确定了德国不同的生物精炼厂产能和最佳位置。此外,可以在县级水平上确定在德国提供必要的生物质原料的地区。最后,我们认为通过多目标优化来扩展 LCA 非常适合指导在技术选择领域中做出明智决定。

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## Assessment of lignocellulosic biorefineries in Germany using a hybrid LCA multi-objective optimization model

Maik Budzinski, Otávio Cavalett, Roy Nitzsche, Anders Hammer Strømman

Keywords: biomass, hybrid LCA, industrial ecology, linear programming, multi-objective

## Summary:

In this study a tiered hybrid life cycle assessment (LCA) multi-objective optimization model is developed and applied to determine the optimal choice of new biorefinery technologies in Germany. Thereby, several aspects can be explicitly addressed, including a regionally differentiated accountability of sustainable feedstock availability, identification of environmental impacts along global value chains, and identification of trade-offs between different sustainability goals. The model is applied to assess the optimal choice between two lignocellulosic biorefinery concepts. Two optimization objectives are taken into account: maximizing the investor's profit and minimizing global impacts on climate change related to a specified demand for products. In terms of environmental impacts, the model also takes into account the comparison of new biorefineries with current available technologies producing the specified final demand. The results of the case study show that the biorefinery concept including the ethylene production is more beneficial in terms of reducing climate impacts, while on the other hand the biorefinery including the ethanol production is more cost-effective. Depending on the decision-maker's preference on weighting the two objectives, different capacities of biorefineries and optimal locations in Germany are identified. Furthermore, regions in Germany providing the necessary biomass feedstock can be identified on a county level. Finally, we argue that the extension of LCA by multi-objective optimization is well suited guiding the way toward well-informed decision-making in the field of technological choices.

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## 消费者行为对淋浴的能量、温室气体和水足迹的影响

作者: [Sadegh Shahmohammad](#), [Zoran Steinmann](#), [Henry King](#), [Hilde Hendrickx](#), [Mark A.J. Huijbregts](#)

**关键字:** 消费者行为, 能源消耗, 温室气体排放, 产业生态学, 变异性评估, 水消耗

**摘要:**

了解消费者行为的多变性可以为如何有效减少与家庭活动有关的环境足迹提供更深层的领悟。本研究开发了一个随机模型来量化四个不同国家（澳大利亚、瑞士、英国和美国）淋浴的能量、温室气体（GHG）和水消耗的足迹，评估了习惯性行为和一次性行为这两个截然不同的行为类别对淋浴的影响，调查了淋浴行为的改变是否对相关的能量、温室气体和水足迹有重大影响。结果表明，由于消费者行为的差异，导致国家内部环境足迹的变化是 6-17 的因子（95 百分位数/5 百分位数），具体取决于国家和所选指标。消费者的理性行为（尤其是选择特定的加热器和淋浴器类型）和习惯性行为（尤其是淋浴时间）都是足迹变化的主要来源。通过做出更好的一次性行为决定，例如购买高效热水器或缩短淋浴时间，可以节省大量资金。

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## The influence of consumer behavior on energy, greenhouse gas, and water footprints of showering

[Sadegh Shahmohammad](#), [Zoran Steinmann](#), [Henry King](#), [Hilde Hendrickx](#), [Mark A.J. Huijbregts](#)

**Keywords:** consumer behavior, energy consumption, GHG emissions, industrial ecology, variability assessment, water consumption

**Summary:**

Understanding variability in consumer behavior can provide further insights into how to effectively reduce environmental footprints related to household activities. Here, we developed a stochastic model to quantify the energy, greenhouse gas (GHG), and water consumption footprints of showering in four different countries (Australia, Switzerland, the United Kingdom, and the United States of America). We assessed the influence of two broadly distinct categories of behavior on the footprints of showering: habitual behaviors and one-off reasoned actions. We also investigated whether changing showering behavior has a substantial impact on the associated energy, GHG, and water footprints. Our results show that the variation in environmental footprints within the countries due to differences in consumer behavior is a factor of 6–17 (95th percentile/5th percentile) depending on the country and the indicator selected. Both consumers' reasoned actions (especially the choice of a specific heater and shower type) and habitual behaviors (length of showering in particular, are the dominant sources of footprint variability. Significant savings are achievable by making better one-off decisions such as buying an efficient water heater and by taking shorter showers.



## 《产业生态学报》

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## 日本食物损失和浪费对全球自然资源和温室气体排放的影响

作者: Yosuke Munesue, Toshihiko Masui

**关键字:** 食物损失和食物浪费, 食品贸易, 温室气体排放, 日本, 自然资源, 可持续食物系统

**摘要:**

日本的粮食供应严重依赖进口。自 2000 年以来, 按热量为基准, 日本的食物自给率一直保持在 40% 左右。据估计, 2012 年日本的食物浪费为 642 万吨 (人均浪费 50 千克)。这些值表明, 食品浪费会导致日本以及向日本出口的国家中的自然资源浪费和过度的温室气体 (GHG) 排放。本研究评测了日本食品中每种食品的浪费, 同时也考虑到畜牧业生产所需的饲料作物, 以评估粮食供应链在加工、分配和消费阶段对土地和水资源的影响以及全球温室气体排放。虽然数据限制带来不确定性, 但经核算发现, 2012 年日本农业生产中浪费粮食造成了 123 万公顷用来生产粮食的土地最终被浪费, 4.13 亿立方米水资源被浪费。此外, 农业生产中不必要的温室气体排放达 351 万吨二氧化碳当量, 国际运输中不必要的温室气体排放达 49 万吨二氧化碳当量。本研究的结果可用于制定亚洲工业化国家的应对食品浪费的对策, 这些国家的食品进口预计将增加, 消费阶段的食品浪费问题预计将与日本目前的情况一样严重。

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## The impacts of Japanese food losses and food waste on global natural resources and greenhouse gas emissions

Yosuke Munesue, Toshihiko Masui

**Keywords:** food loss and food waste, food trade, greenhouse gas (GHG) emissions, Japan, natural resources, sustainable food system

**Summary:**

Japan depends heavily on imports for its food supply. Since 2000, the food self-sufficiency ratio has remained approximately 40% on a caloric basis. Japanese food wastage (i.e., food losses and food waste) is estimated to have been 6.42 million tonnes (50 kg per capita of wastage) in 2012. These values indicate that food wastage leads to wasted natural resources and excessive greenhouse gas (GHG) emissions both in Japan and in countries that export to Japan. This study estimates Japanese food wastage by food item to evaluate impacts on land and water resources and global GHG emissions during the processing, distribution, and consumption phases of the food supply chain while also considering the feed crops needed for livestock production. Despite uncertainties due to data limitations, in 2012, 1.23 million hectares of harvested land were used to produce food that was eventually wasted, and 413 million m<sup>3</sup> of water resources were wasted due to Japanese food wastage in agricultural production. Furthermore, unnecessary GHG emissions were 3.51 million tonnes of CO<sub>2</sub> eq. in agricultural production and 0.49 million tonnes of CO<sub>2</sub> eq. in international transportation. The outcomes of the present study can be used to develop countermeasures to food wastage in industrializing Asian countries where food imports are projected to increase and food wastage issues in the consumption stage are expected to become as serious as they currently are in Japan.

## 《产业生态学报》

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### 产业生态学与企业的边界

作者: [Thomas Magnusson](#), [Hans Andersson](#), [Mikael Ottosson](#)

关键字: 经营策略、多元化、产业组织、产业共生、组织边界、外包

#### 摘要:

如何界定组织边界对制造企业(manufacturing firm)的策略来说非常关键。本文汇集了产业生态学和商业策略的概念和发现, 以便了解制造企业如何参与旨在促进工业废弃物回收的计划。根据废物回收与回收资源再利用之间的区别, 本文介绍了四种不同的策略类型: 封闭、外包、多元化和开放。每种策略都有其独特的组织边界, 并与不同制造企业的动机和利益相关联。各个策略的类型学研究为协助工业管理者进行战略决策提供了概念上的贡献, 并支持对产业生态学中的组织边界问题做进一步研究。

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### Industrial ecology and the boundaries of the manufacturing firm

[Thomas Magnusson](#), [Hans Andersson](#), [Mikael Ottosson](#)

**Keywords:** business strategy, diversification, industrial organization, industrial symbiosis, organizational boundaries, outsourcing

#### Summary:

Decisions on organizational boundaries are critical aspects of manufacturing firms' business strategies. This article brings together concepts and findings from industrial ecology and business strategy in order to understand how manufacturing firms engage in initiatives to facilitate recycling of process wastes. Based on a distinction between waste recovery and use of the recovered resources, the article introduces a typology of four different strategies: Closed, Outsourcing, Diversification, and Open. Each strategy has a unique set of organizational boundaries and is associated with different motives and benefits for the manufacturing firm. The typology of strategies provides a conceptual contribution to assist industrial managers in strategic decision-making, and to support further studies on organizational boundaries in industrial ecology research.

## 《产业生态学报》

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## 原材料关键性评估作为对环境生命周期评估的补充: 产品级供应风险评估的方法探究

作者: Alexander Cimprich, Vanessa Bach, Christoph Helbig, Andrea Thorenz, Dieuwertje Schrijvers, Guido Sonnemann, Steven B. Young, Thomas Sonderegger, Markus Berger

**关键字:** 关键原材料、产业生态学、生命周期评估、生命周期可持续性评估、原材料关键性评估、供应风险

**摘要:**

现代产品中使用的原材料多种多样, 资源的地质分布不均以及诸如生产集中度和原料生产国政治稳定性等社会经济因素会带来供应中断的风险, 这些问题已引发人们对原材料“关键性”的关注。在本文中, 我们回顾了可以作为对环境生命周期评估的补充的有关集成关键性评估(在此称为“产品级供应风险评估”)的最新技术。我们基于一组标准(包括对数据源、不确定性和其他有争议的方法论方面的考虑), 描述并比较了明确为此目的而开发的三种方法: 地缘政治供应风险(GeoPolRisk), 经济稀缺潜力(ESP)和资源效率评估综合方法(ESSENZ)。我们在欧洲制造的电动汽车的案例研究中测试了这些方法, 并在适当应用和解释的指导下进行了总结, 为进一步的方法学发展提供了机会。尽管GeoPolRisk、ESP和ESSENZ方法有一些局限性, 但它们可用于初步评估原材料供应风险对产品系统的潜在影响(即“由外而内”的影响)以及产品系统对环境的影响(即“由内而外”的影响)。未来方法论开发可解决区域和公司层面的供应风险、供应链的多个阶段以及材料回收利用问题, 同时改善供应风险特征因子的覆盖范围。

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## Raw material criticality assessment as a complement to environmental life cycle assessment: Examining methods for product-level supply risk assessment

Alexander Cimprich, Vanessa Bach, Christoph Helbig, Andrea Thorenz, Dieuwertje Schrijvers, Guido Sonnemann, Steven B. Young, Thomas Sonderegger, Markus Berger

**Keywords:** critical raw materials, industrial ecology, life cycle assessment, life cycle sustainability assessment, raw material criticality assessment, supply risk

**Summary:**

The diversity of raw materials used in modern products, compounded by the risk of supply disruptions—due to uneven geological distribution of resources, along with socioeconomic factors like production concentration and political (in)stability of raw material producing countries—has drawn attention to the subject of raw material “criticality.” In this article, we review the state of the art regarding the integration of criticality assessment, herein termed “product-level supply risk assessment,” as a complement to environmental life cycle assessment. We describe and compare three methods explicitly developed for this purpose—Geopolitical Supply Risk (GeoPolRisk), Economic Scarcity Potential (ESP), and the Integrated Method to Assess Resource Efficiency (ESSENZ)—based on a set of criteria including considerations of data sources, uncertainties, and other contentious methodological aspects. We test the methods on a case study of a European-manufactured electric vehicle, and conclude with guidance for appropriate application and interpretation, along with opportunities for further methodological development. Although the GeoPolRisk, ESP, and ESSENZ methods have several limitations, they can be useful for preliminary assessments of the potential impacts of raw material supply risks on a product system (i.e., “outside-in” impacts) alongside the impacts of a product system on the environment (i.e., “inside-out” impacts). Care is needed to not overlook critical raw materials used in small amounts but nonetheless important to product functionality. Further methodological development could address regional and firm-level supply risks, multiple supply-chain stages, and material recycling, while improving coverage of supply risk characterization factors.

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## 哥伦比亚非法作物替代政策的生命周期分析和社会经济分析

作者: Juanita Barrera-Ramírez, Valentina Prado, Håvar Solheim

**关键字:** 可卡因生产, 哥伦比亚, 生命周期分析, 和平协议, 社会经济分析, 替代政策**摘要:**

哥伦比亚和平协议提出了一项非法作物替代政策, 力求用合法作物替代古柯作物。种植合法作物会使一些本应流入农民手中的非法活动的资金改变其用途, 但种植合法作物也会为农民提供收入。因此, 如何评估这项政策的效果需要了解种植合法作物(咖啡树、甘蔗和可可树)如何影响农民的收入, 以及种植合法作物是否比种植非法作物具有环境优势。本研究结合生命周期分析(LCA)和社会经济指标对哥伦比亚两个地区(Putumayo 和 Catatumbo)的不同政策情景进行分析。生命周期分析结果表明, 一项政策的成功并不能保证环境影响最低。与种植古柯作物相比, 种植合法作物消耗的燃料少, 这减少了与燃料有关的环境影响。但咖啡种植过程需要使用肥料和甘蔗种植过程需要使用农药, 这就使与毒性相关的环境影响指标有所增加。然而, 本研究所得结果与所涉及到的化学产品的一些特性有关, 在分析过程中一旦这些特性可以定量化评估, 种植古柯作物的毒性影响指标会更大。就单个作物而言, 种植可可作物对环境的影响要比种植咖啡和甘蔗低, 但花费时间最长, 这可能会增加农民的财政风险。社会经济分析结果表明, 非法作物替代政策的成功, 会减少 Catatumbo 地区农民的收入, 但会增加 Putumayo 地区农民的收入, 同时提供更多的就业机会。总的来说, 非法作物供应链因地区而异, 这也会影响非法作物替代政策的环境影响评估和社会经济分析结果。

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## Life cycle assessment and socioeconomic evaluation of the illicit crop substitution policy in Colombia

Juanita Barrera-Ramírez, Valentina Prado, Håvar Solheim

**Keywords:** cocaine production, Colombia, life cycle assessment (LCA), peace treaty, socioeconomic analysis, substitution policy**Summary:**

The peace treaty of Colombia contemplates a crop substitution policy seeking to replace coca crops with legal alternatives. Although crop substitution diverts funding of illegal activities and provides an income to farmers, it is important to understand how the change to a variety of legal crops (coffee, sugarcane, and cacao) affects the income of farmers, and whether there is an environmental advantage of a crop over another. This study applies life cycle assessment (LCA) coupled with socioeconomic indicators to two regions, Putumayo and Catatumbo, over different policy scenarios. LCA results show that a policy success does not ensure a lower environmental impact across the board. Legal crops consume less fuel than coca crops, which reduce fuel-related impacts, but the use of fertilizer in coffee and pesticide use in sugarcane increase toxicity-related impacts. The results, however, are affected by a lack of characterization factors of agrochemicals, but once these are replaced by proxies, coca crops appear to have greater toxicity impacts. In terms of individual crops, cacao crops have a lower environmental impact than coffee and sugarcane, but it also takes the longest to harvest, which may pose a financial risk to farmers. The socioeconomic analysis reveals that for Catatumbo farmers, a policy success reduces the income, whereas for Putumayo farmers, a policy success increases income and job generation. In general, it was observed that the dynamics of the illegal supply chain vary for each region, influencing the environmental and socioeconomic outcome of the substitution policy.

## 《产业生态学报》

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## 包装引起的食品生产和消费者行为变化的环境分析

作者: Naoki Yokokawa, Emi Kikuchi-Uehara, Eri Amasawa, Hirokazu Sugiyama, Masahiko Hirao

**关键字:** 消费模式, 有效期, 食物损失和浪费, 生命周期评估 (LCA), 包装功能, 情景分析

**摘要:**

本研究分析了由包装引起的食品生产和消费者行为变化对环境的影响, 以帮助包装设计者做出具有环保意识的决策。包装可以功能化以防止食物损失和浪费 (FLW), 例如, 延长保质期和采用不同的包装尺寸, 但是食品和包装生产可能会产生额外的环境影响。先前的研究评估了包装生产的其他影响, 然而, 包装功能化的影响尚未与食品生产和消费者行为相关联。为了检验功能化对这些方面的影响, 我们分析了牛奶和卷心菜产品由包装所致的食品生产的变化。该案例研究比较了功能化包装的产品, 允许更长的保质期或更小份额包装的产品。我们的研究表明, 与其他过程相比, 源自包装的变化增加了食品生产过程的全球变暖潜能 (GWP)。因此, 食品生产的变化削弱了包装功能化降低全球变暖潜能值的有效性。此外, 对消费者行为情景的分析表明, 消费者对产品失效日期的感知将决定性地影响包装功能化的有效性。当消费者在有效期之后丢弃食品时, 只要他们少量消费, 包装功能化就减少了粮食损失与浪费。从方案分析中, 我们发现包装功能化和消费者行为的适当组合可有效降低总 GWP。通过扩展分析, 包装设计人员可以了解到他们在产品生命周期中做出的决策能够有效减少 FLW 和环境影响。

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## Environmental analysis of packaging-derived changes in food production and consumer behavior

Naoki Yokokawa, Emi Kikuchi-Uehara, Eri Amasawa, Hirokazu Sugiyama, Masahiko Hirao

**Keywords:** consumption pattern, expiration date, food loss and waste, life cycle assessment (LCA), packaging functionality, scenario analysis

**Summary:**

This study analyzed the environmental impacts of packaging-derived changes in food production and consumer behavior to assist packaging designers in making environmentally conscious decisions. Packaging can be functionalized to prevent food loss and waste (FLW), for example, extending the expiration date and apportioning the package size, but it can generate additional environmental impacts from changes in food and packaging production. Previous studies assessed additional impacts from packaging production; however, the effects of packaging functionalization are yet to be connected with food production and consumer behavior. To examine the effect of functionalization on these aspects, we analyzed packaging-derived changes in food production for milk and cabbage products. The case study compared products with functionalized packaging that permits a longer expiration date or a smaller portion size to their base-case products. Our results showed that the packaging-derived changes increased the global warming potential (GWP) of food production more than other processes did. Thus, changes in food production weakened the effectiveness of the packaging functionalization to decrease the GWP. Moreover, the analysis of consumer behavior scenarios showed that consumers' perception of the expiration date decisively influences the effectiveness of packaging functionalization. When consumers discarded food after the expiration date, provided they consumed in small quantities, the packaging functionalization reduced FLW. From the scenario analysis, we identified appropriate combinations of packaging functionalization and consumer behaviors to effectively decrease total GWP. With our expanded analysis, packaging designers can understand the effectiveness of their decisions on the product life cycle in reducing FLW and environmental impacts.

## 《产业生态学报》

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## 迈向矿产关键性的动态评估: 引入关键性的系统评估框架

作者: Ye Yuan, Mohan Yellishetty, Mario A. Muñoz, Stephen A. Northey

关键字: 复杂系统、动态系统、产业生态学、矿产关键性、统计学习、供应风险

## 摘要:

本文提出了一套新的矿产关键性评估方法体系。该体系考虑了矿产市场中四类主体: 矿产供应者、消费者、市场监管者以及其他相关主体(例如, 矿区周边的社区团体等)。该体系将各个主体之间的复杂机制及相关变量归纳为三类:

- 1) 约束作用, 例如矿区的政治稳定性、矿物的可替代性和经济重要性等;
- 2) 交互作用, 例如买卖双方的议价等;
- 3) 交互变量, 例如需求、供应和价格等。

该方法体系可用于不同矿产的关键性分析与评估, 通过比较分析得出矿产的相对重要性。本文所构建的方法体系也可用于矿产关键性的动态分析与评估。

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## Toward a dynamic evaluation of mineral criticality: Introducing the framework of criticality systems

Ye Yuan, Mohan Yellishetty, Mario A. Muñoz, Stephen A. Northey

Keywords: complex systems, dynamic systems, industrial ecology, mineral criticality, statistical learning, supply risk

## Summary:

A new methodology to quantify minerals' criticalities is proposed—the criticality systems of minerals. In this methodology, four types of agents—mineral suppliers, consumers, regulators of the market, and others, such as the communities near mining operations—interact with each other through three types of indicators: constraints, such as the political stability in the mining regions, the mineral's substitutability and economic importance; agents' interactions, such as buyer–seller bargaining; and interactive variables, such as the demand, supply, and price. When the criticality systems of two mineral groups are constructed, analyses that compare the indicators of these criticality systems can determine which group is more critical than the other. This methodology allows evaluation of criticality in a dynamic and systemic manner.

## 《产业生态学报》

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## 如何监控循环经济的环境压力: 指标评估

作者: [Hanna Helander](#), [Anna Petit-Boix](#), [Sina Leipold](#), [Stefan Bringezu](#)**关键字:** 环境压力, 足迹, 产业生态学, 评述, 社会经济代谢, 可持续资源利用**摘要:**

了解循环经济 (CE) 如何减少经济活动带来的环境压力对于政策和实践至关重要。一系列科学指标用于监控和评估 CE 活动。但是, 常见的 CE 活动 (例如回收和生态设计) 就其对环境可持续性的贡献方面存在争议。本文评估当前评估 CE 活动的方法是否或在何种程度上足以捕捉环境压力从而监测环境可持续性的进展。基于物质流视角, 本研究表明大多数指标并未反映与其相关的 CE 活动的环境压力。许多研究只关注单一的 CE 活动或过程, 但这不一定有助于整体提高环境可持续性。基于以上结果, 我们建议用与 CE 活动相关的基本环境压力指标来补充 CE 管理指标。考虑到 CE 活动, 资源提取和废物流之间的概念联系, 我们建议采用一种基于资源的足迹方法来解释主要的环境投入和产出, 尽管这还不足以评估 CE 活动的环境可持续性。由于足迹方法可以在不同规模上使用, 因此可以帮助制定具有挑战性的指标, 以监控在欧洲、国家和公司层级的环境可持续 CE 进展。

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## How to monitor environmental pressures of a circular economy: An assessment of indicators

[Hanna Helander](#), [Anna Petit-Boix](#), [Sina Leipold](#), [Stefan Bringezu](#)**Keywords:** environmental pressure, footprints, industrial ecology, review, socioeconomic metabolism, sustainable resource use**Summary:**

Understanding how a circular economy (CE) can reduce environmental pressures from economic activities is crucial for policy and practice. Science provides a range of indicators to monitor and assess CE activities. However, common CE activities, such as recycling and eco-design, are contested in terms of their contribution to environmental sustainability. This article assesses whether and to what extent current approaches to assess CE activities sufficiently capture environmental pressures to monitor progress toward environmental sustainability. Based on a material flow perspective, we show that most indicators do not capture environmental pressures related to the CE activities they address. Many focus on a single CE activity or process, which does not necessarily contribute to increased environmental sustainability overall. Based on these results, we suggest complementing CE management indicators with indicators capturing basic environmental pressures related to the respective CE activity. Given the conceptual linkage between CE activities, resource extraction, and waste flows, we suggest that a resource-based footprint approach accounting for major environmental inputs and outputs is necessary—while not sufficient—to assess the environmental sustainability of CE activities. As footprint approaches can be used across scales, they could aid the challenging process of developing indicators for monitoring progress toward an environmentally sustainable CE at the European, national, and company levels.

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## 发展中国家以报废产品管理作为弹性驱动力: 厄瓜多尔的旧轮胎政策试验

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关键字: 适应性治理, 生产者责任延伸制度, 非正式性, 自然灾害, 弹性, 旧轮胎

## 摘要:

在过去的几十年中, 管理者设计了许多新的环境政策来改善废弃物管理。其中, 生产者责任延伸制度 (EPR) 将报废产品的环境和财务负担从公共管理转移到生产者, 已被越来越多的发展中国家所采用。然而, 该政策在实施过程中经常会受到阻碍, 从而错过了将废物管理用作可持续发展动力的机会。通过讨论厄瓜多尔废旧轮胎的 EPR 制度, 本文提出了在发展中国家设计和实施 EPR 计划的另一种方法: 它建议考虑社会可持续性, 而不仅仅是复制国外管理框架。基于该设想, 本文设计并实施了两个针对社会导向的废旧轮胎 (end-of-life tires, ELTs) 应用的案例研究, 旨在通过应用土木工程来增加住区对灾难性事件的抵抗力, 从而提高脆弱人群对自然灾害的抵御能力。厄瓜多尔的案例还凸显了在处理具有挑战性的城市管理主题时采用自适应治理方法的好处, 此类主题包括非正式性 (发展中国家普遍存在的现象) 和弹性等。

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## End-of-life product management as a resilience driver for developing countries: A policy experiment for used tires in Ecuador

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Keywords: adaptive governance, extended producer responsibility, informality, natural hazards, resilience, used tires

## Summary:

Over the last decades, a number of new environmental policies have been designed to improve waste management. Among them, extended producer responsibility (EPR) has introduced a mechanism to shift the environmental and financial burden of end-of-life products from public management to producers. Recently, EPR has been adopted by a growing number of developing countries, but this policy often struggles in being effectively implemented in such contexts, missing the opportunity of using waste management as a sustainability driver. By discussing the EPR for end-of-life tires (ELTs) in Ecuador, this paper proposes a different approach in designing and implementing EPR schemes in developing countries: it recommends consideration of social sustainability, rather than merely copying foreign management frameworks. To address this point, two case studies on socially directed ELT applications were designed and carried out. The case studies aimed at improving resilience of vulnerable populations to natural disasters by increasing the resistance of housing and settlements against catastrophic events using civil engineering applications. The analysis of the case studies' outcomes brings to light possible policy adjustments, in which social sustainability goals are taken into account within the national EPR scheme. The Ecuadorian case also highlights the benefit of employing an adaptive governance approach when dealing with challenging urban management topics, such as informality (a widespread phenomenon in developing countries) and resilience.