Available online at www.sciencedirect.com
ScienceDirect
Journal of Cleaner Production 15 (2007) 1706–1715
Journal of Cleaner Production
www.elsevier.com/locate/jclepro

Material flow analysis adapted to an industrial area

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Accepted 4 August 2006
Available online 9 October 2006

Abstract

Material flow analysis (MFA) has become a useful tool for industrial ecology (IE) to analyze the metabolism of social systems, such as countries and regions. This paper proposes to use the indicators derived from MFA, complemented with water and energy indicators, to analyze the efficiency and the materialization ranks of industrial areas. The methodology is applied to a case study of an industrial area located in Catalonia (Spain). Despite the heterogeneity of the area, by using simple data the indicators detect companies with high consumption or inefficiency. These companies have many opportunities to improve on these aspects and the indicators can measure and reflect their evolution. In addition, the results show the importance that some flows such as water inputs (1.5 times higher than material inputs) and indirect flows associated with imports, which often are omitted, can have in some study cases.

Keywords: Industrial symbiosis; Industrial ecology; Material flow analysis (MFA); Environmental indicators; Industrial park

1. Introduction

Despite its youth, industrial ecology (IE) has become a recognized field in the scientific community, with burgeoning literature to furnish its definition and its analogy with natural ecosystems. Many experiences have begun and are working around the world, where IE is applied at different levels: from global or national level to company level (for an overview, see the special issue on Industrial Ecology in the Journal of Cleaner Production [1]).

Some of the most innovative and relevant IE contributions have been the broader perspective with which it analyses industrial systems, and how IE proposes to transform industrial areas into eco-industrial parks (EIP). IE handles industry integrated in its surroundings from an environmental point of view, without compromising or deteriorating its economic and social sustainability. The field goes beyond the improvement of manufacturing practices and focuses on the interrelations between the company and its surroundings, whether that is cities, other companies or regions [2]. In fact, a report from the US Environmental Protection Agency defined EIP as a "*community of manufacturing and services companies seeking enhanced environmental and economic performance through collaboration in managing environmental and resources issues including energy, water and materials… Through collaboration, this community of companies can become an industrial ecosystem*" [3].

One of the strong points of EIP is the cooperation between businesses to find win–win situations, where the benefits of cooperation should be greater than the sum of individual advantages. Despite the efforts invested and the attractive definition of EIP, there are few experiences and many problems arise when implementing IE in industrial areas [4]. First, the success of EIP depends on many variables [5], but time and active company participation are crucial to establish networking, especially in the conversion of existing industrial areas. Thus, the project of conversion is usually a slow and progressive evolution towards an EIP. In this context, indicators are

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doi:10.1016/j.jclepro.2006.08.019

necessary and useful in order to objectively reflect and measure this constant evolution. Secondly, the larger the area analyzed, the easier it is to find these types of situations and the greater the opportunities. Nowadays, some interesting projects can be found at regional level [6,7]. Moreover, this system growth leads to a rise in flows and data analyzed, thus increasing the complexity of the system. This is when the need to find tools to simplify the system emerges. Indicators capable of structuring and simplifying systems data can be one of these tools.

There is an extensive bibliography on indicators and many have been already defined [8,9]. In general, a good indicator should be credible, transparent, relevant, accurate, measurable, cost effective, comparable, adaptable, able to show changes, and readily understood [10]. Many times the estimation of some indicators requires a high amount of precise data and in other cases complicated ways of estimation result in final numbers with no physical meaning. These are precisely the advantages of material flow analysis (MFA) derived indicators.

MFA is a widespread and standardized methodology [11] for accounting the input and output material flows of a system, and for estimating their derived environmental indicators [12]. All flows and indicators are measured in mass units, giving a physical quantification of the system's material requirements. The methodology has been mostly applied to countries and regions in order to analyze their social metabolism [13,14], but not to industrial areas. At this scale it is more frequent to apply input–output analysis, substance flow analysis and other similar methodologies [15–17], as it is to apply environmental management accounting to companies [10]. However, the added value in applying MFA at this level is quantifying all material flows and finding meaningful and simple indicators that will be able to detect critical points and reflect the state and evolution of the system's metabolism.

The aim of this paper is to adapt MFA methodology to apply it to an industrial park and the companies located within it, and to show the results obtained for an industrial area located in Catalonia.

2. Analytical framework

To apply material flow accounting to the industrial park and to the companies, the Eurostat [11] methodology was adapted and complemented with energy and water indicators. This section summarizes the distinctive features of the methodology used.

2.1. System boundaries

The material flow analysis was applied to each company and to the industrial area as a whole. Each company represented a ''subsystem'' which formed part of the total industrial area, the ''system''. All subsystems and the overall system were to obey the material flow balance, but the global balance was not the sum of each subsystem's balance. Subsystems boundaries were defined by the territorial limits of the companies and the system area is the sum of the company's areas. Consequently, if all the companies of the industrial park participate in the project, the system boundaries will coincide with the geographical limits of the industrial park.

In the case that one company or enterprise has more than one factory, only the factories inside the system boundaries will be included in the analysis.

2.2. Flows

The classification of flows was analogous to Eurostat classification [11]. Domestic extraction was the resources used extracted inside the system, whereas raw materials and products from other businesses, bought or extracted outside the industrial area, were treated as imports. Exports were the products and materials used or sold outside the system boundaries, while emissions to air, wastes and wastewater were outputs to the environment.

When applying MFA at company level, as well as at national level, indirect flows associated with imports and exports may or may not be accounted. Nevertheless, indirect flows of the whole industrial area should not be accounted as the sum of the indirect flows associated with each company, in order to avoid double counting. For the same reason, by-products do not have associated indirect flows; except in the case of materials specially used to modify by-product characteristics in order to improve or reuse them.

Although water and air are strictly materials, they are considered as independent flows, as in MFA at national level, due to the large amounts used. Material flow indicators only take into account the amount of water and air used in manufacturing processes. The rest is included in independent indicators.

2.3. Significant issues in the adaptation of MFA to industrial parks

When MFA for national economies or regions is adapted to industrial parks, some aspects should be pointed out:

1. MFA should be combined with energy and water flow analysis, as it is important to measure all the resources used by the system. Depending on the park's location, both resources can suppose important environmental impacts. Also, situations in which material decreases at expenses of energy or water consumption (i.e. recycling), should be detected. Finally, in an EIP, as the use of all resources, not only materials, should be improved, all should be quantified.
2. Whereas at national level most of the data are statistical, in industrial parks data are given by the companies, reflecting better the reality and the system's heterogeneity. Additionally, indirect flows associated to companies' production should be estimated in situ, because the coefficient used at national level could give erroneous values. Furthermore, the results of indirect flows for industrial parks could be used in the development of statistical basis to estimate indirect flows at national or regional level.