1 Introduction and Overview

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1.1 Introduction

The up-and-coming field known as "industrial ecology" is currently dominated by descriptive and design studies of physical processes and technical solutions that leave out relevant economic conditions and mechanisms. The main motivation for this book is that such an approach is insufficient to provide policymakers and business managers with economically feasible, cost-effective, and socially supported instruments and solutions. The approach presented here therefore aims to integrate the natural science and technological dimensions of industrial ecology with an economic angle. Various authors in the field of industrial ecology have strongly recommended such a synthesis (e.g., Koenig and Cantlon 2000; Fischhoff and Small 2000; Brunner 2002). The main value of adding economics to industrial ecology can best be summarized as increasing policy realism. Combining economics with industrial ecology will entail three elements that are largely lacking from the current literature on industrial ecology:

1. Adding an economic context to industrial ecology, in the form of costs, benefits, economic efficiency considerations, (re)allocations, investments, market processes and distortions, economic growth, multisectoral interactions, international trade, and so forth.
2. Showing the usefulness of a range of concepts, theories, and methods for the integration of economics and industrial ecology in empirical applications. Examples are structural decomposition analysis, (general) equilibrium analysis, complex systems modeling, econometric-statistical analysis, dynamic input-output modeling, urban and regional economics, theories of the firm, and institutional and evolutionary economics.
3. Deriving general policy lessons based on the integration of economic and industrial ecology considerations at a theoretical level, as well as on

the insights of empirical case studies. In essence, this means combining lessons about physical, technical, and economic opportunities as well as about their limitations.

To motivate the idea that industrial ecology lacks a coherent and thorough treatment of relevant economic dimensions, let us consider authoritative surveys of and outlets for insights and research in the field of industrial ecology. Socolow et al. (1994), Graedel and Allenby (2003), and Ayres and Ayres (2002) are very representative of the insights that the field has delivered so far, and the *Journal of Industrial Ecology* allows us to trace recent research themes and trends. Socolow et al. (thirty-six chapters in 530 pages) is so broad that it really holds the middle ground between a text on industrial ecology and one on environmental science, covering issues from the firm to the global level. It contains two chapters that deal with economics, one analyzing principal-agent problems at the level of firms, and another studying raw materials extraction and trade. Although useful, these chapters can certainly not be regarded as anything close to a complete treatment of economic dimensions as previously outlined. Graedel and Allenby (twenty-six chapters in 363 pages) more clearly steps away from traditional environmental science and is strong on firm-level and manufacturing issues but lacks any treatment of economic considerations, be it at the firm or the economy-wide level. Ayres and Ayres (forty-six chapters in 680 pages) includes an entire section on the theme "Economics and Industrial Ecology," which consists of seven very short chapters. But it turns out that several of these chapters do not really address economic issues at all, but instead focus on physical indicators (Total Material Requirement, or TMR), exergy, transmaterialization, and technology policy. The chapters that do deal with economic issues survey the inclusion of material flows in economic models, the empirical relationship between dematerialization and economic growth, and the literature on optimal resource extraction. Again, this is useful but does not represent a sufficiently broad coverage of economic issues.

In effect, from reading both these books and the *Journal of Industrial Ecology*, one can easily obtain the impression that industrial ecology completely lacks economic considerations and instead is mainly about technological planning and design. At the aggregate level, this is perhaps most clearly reflected in the well-known Factor X debate ($X = 10$ in the case of Factor Ten Club 1994, and $X = 4$ in the case of von Weizsäcker et al. 1997). A scan of all the issues of the *Journal of Industrial Ecology* (twenty-three in seven volumes) delivered a disappointingly small number of articles that address (and then often only tangentially) economic reasoning or methods (these articles are mentioned in the literature survey presented in chapter 2). The planning-and-design perspective strongly contrasts with the economics perspective, which emphasizes firm behavior (strategies, routines, and input-mix decisions that affect material use), market processes (liberalization and decentralization), and economy-wide feedback involving prices, incomes, foreign trade, change in sector structure and intermediate deliveries, shifts in consumer expenditures, and market-based policy instruments. One can conclude that, with regard to the three elements listed earlier, (1) and (2) have received very little to no attention in the literature on industrial ecology. Instead, all method-related developments and empirical work have focused on noneconomic methods like material and substance flow analysis, life cycle analysis, and process and product design. Given the neglect of these first two elements, element (3) has evidently not been accomplished.

Economists have long been interested in the impact that economies have on natural resources and the environment and the negative feedback this may provide to welfare and economic growth (van den Bergh 1999). This interest has, inter alia, resulted in studies that examine the relationship between physical flows through the economy, on the one hand, and market functioning, economic growth, international trade, and environmental regulation, on the other. Early work that combined economics and material flow analysis started with the methodological studies by Ayres and Kneese (1969), Kneese, Ayres, and D'Arge (1970), and Georgescu-Roegen (1971). Much of the subsequent work focused on input-output and other types of economic models, with extensions to account for polluting residuals (James 1985). Boulding (1966) and Daly (1968) can be seen as conceptual predecessors of this line of thought. In the context of his "steady state," Daly (1977) proposes the idea of reducing or minimizing the physical resource "throughput" that runs through the economy, which closely meets the approach of industrial ecology. Daly and Townsend (1993) presents a collection of reprinted classic articles on the boundary of philosophy, economics, and environmental science, many of which are imbued with the spirit of industrial ecology.

The emergence of the field of industrial ecology since the 1990s has stimulated a great deal of methodologically well-founded research that is aimed at measuring, describing, predicting, redirecting, and reducing physical flows in economies. The current book intends to offer a balanced combination of environmental-physical, technological, and economic considerations. This is believed to provide the best basis for identifying opportunities to reduce pressures on the environment that are linked to material flows, as well as to design public policies to foster such opportunities. A brief overview of the relevant literature on the interface between economics and industrial ecology is provided in chapter 2. In addition, the book presents new and original studies that try to accomplish a close link between economics, in particular environmental and resource economics, and industrial ecology. These have not yet influenced the dominant themes in industrial ecology—witness the critical evaluation from an economic perspective of the representative books and the field journal earlier in the chapter.

Research on industrial metabolism has emphasized the description of material flows in economic systems (Daniels and Moore 2002 and Daniels 2002 offer a good overview of all the methods and their applications). Studies along these lines provide interesting and useful information about the size of material flows and the identification of stocks in which certain undesirable materials accumulate. This leads to concepts like "chemical time bombs" (e.g., the accumulation of chemicals in river mud) and "waste mining" (i.e., beyond a certain point, material waste that has accumulated in certain locations can be turned into a resource suitable for profitable mining) (e.g., Bartone 1990; Allen and Behmanesh 1994). Nevertheless, several relevant issues cannot be addressed properly with a descriptive industrial ecology approach. One reason is that the "metabolism" of economic systems changes over time, which cannot be understood simply by the measurement of material flows. An understanding of the relationship between economic activities and material flows can help to unravel the socioeconomic causes of both the physical flows and the changes therein. An analytical approach to this problem requires that attention be given to, inter alia, the behavior of economic agents like producers and consumers, interactions among stakeholders in production chains, the spectrum of technological choices, and the role of trade and interregional issues. At a more abstract level, such an approach involves substitution and allocation mechanisms at the level of production technologies, firms, sectors, and the composition of demand. In other words, besides a description of material flows, the field of industrial ecology requires a comprehension of the processes behind the material flows. A deeper understanding of the processes leading to changes in material flows can also provide insight into how to develop both effective and efficient policies that lead to a reduction in harmful material flows. In addition, the notion of rebound effects can be seriously examined. This notion comprises the whole range of indirect technological and economic consequences of certain technological scenarios. Such indirect effects can be induced by, or run through, alterations in prices, changes in market demand and supply, substitution in production or consumption, growth in incomes, and changes in consumer expenditures. A better grip on the sign and magnitude of rebound effects is needed to counter simplistic technology-based arguments in favor of certain policy or management strategies and to temper naïve expectations about what can be achieved over certain periods of time with technology. This is relevant, for example, when estimating the impacts of rapid changes in information and communication technology on material flows.

This book provides a unique overview of different economic approaches to address problems associated with the use of materials in economic systems at different levels. Some of these approaches have economics at the core, whereas others add economic aspects to technological or natural-science-dominated approaches or applications. The major part of the book offers a collection of new studies that cover a wide range of approaches and methods for integrating physics and technological analysis and knowledge with economics. The scale varies from industrial parks in Denmark and the Netherlands to the international trade of waste. The variety of approaches can be explained by the fact that the diversity and complexity of topics on the boundary of economics and industrial ecology—indicated by the dimensions: materials, technology, physics, economics, and varying (spatial and aggregation) scales—cannot be completely covered with a single approach. As a result, the book reflects a pluralistic approach.

The contributions have been organized in four themes (parts II to V). The first theme (chapters 3 and 4) is concerned with the historical analysis of structural change. The second theme (chapters 5 to 8) covers a range of models that try to predict future structural change under different policy scenarios. The third theme (chapters 9 and 10) addresses two models that can be used to examine waste management and recycling opportunities. Finally, the fourth theme (chapters 11 and 12) adopts a local-scale perspective by focusing on the dynamics of eco-industrial parks. Chapter 13 closes the book with a summary and synthesis of policy implications.

1.2 Historical Analysis of Structural Change

Chapters 3 and 4 offer different (statistical and decomposition) approaches to the historical analysis of the impact of structural change on material flows through the economy. In chapter 3, Ayres, Ayres, and

Warr challenge the widespread idea of dematerialization by presenting data on the major commodity flows in the U.S. economy since 1900, in both mass and exergy terms. Based on these data, the U.S. economy turns out not to be "dematerializing," to any degree that has environmental significance. Since 1900 it has exhibited a slow and modest long-term increase in materials consumption per capita, except during the Depression and World War II. The trends with regard to resource productivity (gross domestic product [GDP] per unit of materials consumption) are moderately increasing overall. Ayres et al. argue that policy should focus not on reducing the total mass of materials consumed, but on reducing the need for consumables, especially intermediates.

In chapter 4, Hoekstra and van den Bergh present a quantitative historical analysis based on the method of input-output (I/O) structural decomposition analysis (SDA). They open with an overview of the literature on SDA. This method uses historical I/O data to identify the relative importance of a wide range of drivers. SDA has been applied in studies of energy use and energy-related emissions, but only once (in unpublished work) of material flows. The authors carry out a decomposition of the use of iron and steel and plastics products in the Netherlands for the period 1990–1997. This is based on a new data set, unique in the world, which incorporates hybrid-unit input-output tables. The data were constructed especially for the present purpose in cooperation with the national statistical office of the Netherlands, through a construction process that is briefly discussed. Finally, an illustration is given of how the results of SDA can serve as an input to a forecasting scenario analysis.

1.3 Projective Analysis of Structural Change

Chapters 5 to 8 present case studies on regional and national scales that employ a range of modeling approaches. In chapter 5, Ruth, Davidsdottir, and Amato describe a model that combines engineering and econometric techniques for the analysis of the dynamics of large industrial systems. A transparent dynamic computer modeling approach is chosen to integrate information from these analyses in ways that foster the participation of stakeholders from industry and government agencies in all stages of the modeling process—from problem definition and determination of system boundaries to the generation of scenarios and the interpretation of results. Three case studies of industrial energy use in the United States are presented: one each for the iron and steel, pulp and paper, and ethylene industries.

In chapter 6, Foran and Poldy describe two analytical frameworks that have been applied to Australia: namely, the Australian Stocks and Flows Framework (ASFF) and the OzEcco embodied energy flows model. The first (ASFF) is a set of thirty-two linked calculators that follow, and account for, the important physical transactions that underpin our everyday life. The second (OzEcco) is based on the concept of embodied energy, the chain of energy flows from oil wells and coal mines that eventually are included or embodied in every good and service in both the domestic and export components of our economy. Both analytical frameworks are based on systems theory and implemented in a dynamic approach.

In chapter 7, Mannaerts presents STREAM, a partial equilibrium model for material flows in Europe, with emphasis on the Netherlands. The model provides a consistent framework for material use scenarios and related environmental policy analysis of dematerialization, recycling, input substitution, market and cost prices, and international allocation of production capacity. The chapter reports the effects of various environmental policy instruments for Western Europe and the Netherlands, including imposed energy taxation, taxation of primary materials, performance standards for energy and emissions, and deposit money for scrap. Chapter 7 shows that no absolute decline in material use can be found in member countries of the Organization for Economic Cooperation and Development (OECD), but that a relative decoupling of material use and GDP can be observed.

In chapter 8, Idenburg and Wilting present the DIMITRI model, a mesoeconomic model that operates at the level of production sectors, focusing on production and related environmental pressure in the Netherlands. The use of a multiregional input-output structure enables an analysis of changes among sectors and among regions resulting from technological changes. Because of the dynamic nature of the model, it allows analysis not only of the consequences of changes in direct or operational inputs, but also of shifts from operational inputs toward capital inputs and vice versa. Different analyses with the model are presented to show the benefits of a dynamic input-output framework for policy analysis.

1.4 Waste Management and Recycling

Chapters 9 and 10 address modeling of opportunities for waste management and recycling. In chapter 9, Bartelings, Dellink, and van Ierland present a general equilibrium model of the waste market to study market distortions and specifically flat-fee pricing. A numerical example is used to demonstrate the effects of flat-fee pricing on the generation of waste. The results show that introducing a unit-based price will stimulate both the prevention and recycling of waste and can improve welfare, even if implementation and enforcement costs are taken into account. Introducing an upstream tax can provide incentives for the prevention of waste but will not automatically stimulate recycling. A unit-based pricing scheme is therefore a more desirable policy option.

In chapter 10, van Beukering provides an overview of the internalization of waste flows. He focuses attention on the international trade of recyclable materials between developed countries and developing countries. Empirical facts indicate a high rate of growth of such trade. Moreover, a particular trade pattern has emerged, characterized by waste materials being recovered in developing countries and then exported to other developing countries, where they are recycled. Chapter 10 discusses the economic and environmental significance of the simultaneous increase in international trade and the recycling of materials.

1.5 Dynamics of Eco-Industrial Parks

Chapters 11 and 12 deal with industrial ecology dynamics at the lowest scale and consider the self-organization and stimulation of eco-industrial parks. A classic example in industrial ecology is the industrial symbiosis reported in Kalundborg. Both chapter 11 and chapter 12 use the Kalundborg case study as their starting point. The eco-industrial park in Kalundborg is one of the most internationally well-known examples of a local network for exchanging waste products among industrial producers. In chapter 11, Jacobsen and Anderberg offer an analysis of the evolution of the "Kalundborg symbiosis." This case has been studied from different viewpoints. For comparison and contrast, the authors discuss ongoing efforts to develop an eco-industrial park in Avedøre Holme, an industrial district around the major power plant in the Copenhagen area. The chapter closes by addressing the limitations of the Kalundborg symbiosis.

In similar vein, in chapter 12, Boons and Janssen use the Kalundborg example to analyze why there have been so many efforts to re-create Kalundborg in other locations. The main problem of creating an eco-industrial park is to overcome a collective action problem, which is not without costs. But such costs are generally neglected, since most studies look only at benefits from technical bottom-up and top-down designs. As research on collective action problems shows, top-down arrangements are often not effective in creating sustained cooperative arrangements. Furthermore, bureaucrats and designers may not have the required knowledge to see entrepreneurial opportunities for reducing waste flows. Boons and Janssen argue that more may be expected from incentives for self-organized interactions that stimulate repeated interactions and reduce investment costs, or from providing subsidies for investments in interfirm linkages.

1.6 Policy Implications

Finally, in chapter 13, van den Bergh, Verbruggen, and Janssen discuss the policy implications of the research reported here. In particular, the chapter considers the question of whether a combined policy specifically focused on materials and waste is needed. It concludes that a general dematerialization policy is meaningful for a number of theoretical and practical reasons. Dematerialization and waste policy support one another in the long run, even if, in the short run, they are often conflicting. The aim of a combined policy is to facilitate technological innovation and transitions toward a material-poor economy. Policy can attempt to stimulate the incorporation of certain physical requirements into production processes and products, even when from an economic point of view these requirements are second best.

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