Chapter 10
Analysing the Economic Impacts of a Material Efficiency Strategy

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Introduction

One of the fundamental goals of industrial ecology is to change and reduce material and energy flows related to satisfying the needs of human society, so that volume and quality of these flows can be carried by the natural environment without severe disturbances. Among the many redesign strategies proposed in industrial ecology, the strategy of material efficiency improvement mainly targets bulk material flows and aims at producing and using material goods in a more efficient way. Understood in a wider sense, material efficiency improvement also covers material and product substitution which reduces the environmental burden of material goods. As common in the field of industrial ecology, a life cycle view should be chosen to evaluate the efficiency criterion. Thus a higher material efficiency of an alternative design option should be proven over the complete life cycle of a product.

Understood in such a wide sense, options for improving material efficiency can be differentiated into the following main groups[1]:

- Efficient use of materials and material goods in manufacturing and final use
- Materials substitution
- Recycling and reuse of manufacturing wastes, used products and components
- Design of more durable goods and
- Material efficient product substitution, including intensification of product use like in product service systems (Mont 2003)

A characteristic feature of these material efficiency improvement options is that they induce changes not only within certain processes or enterprises, but in various parts of product life cycles and across different economic sectors. If these strategies are

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[1] See Nathani (2003a, b) for further discussion, Worrel et al. (1995) and Gielen (1999) for overviews of the material efficiency concept.

S. Suh (ed.), *Handbook of Input-Output Economics in Industrial Ecology*, Eco-Efficiency in Industry and Science 23,

realized on a large scale they can lead to major changes of societal material flows and shift the division of labor between the sectors of the economy. The relevance of activities such as resource extraction, energy conversion, primary materials manufacturing or waste disposal would probably be diminished. On the other hand waste collection, sorting and processing as well as secondary materials manufacturing would gain in importance. In manufacturing the focus could be shifted from manufacturing new materials to remanufacturing and reuse of products and parts. The need for redistribution logistics as well as accompanying services would probably increase. Changes would also occur in the supply chains of the directly affected enterprises as well as in the industries supplying capital goods. These changes could also affect foreign trade of a country. On balance the realization of a material efficiency strategy could result in a strong impetus on structural change in the economy and further macroeconomic impacts. Therefore it is important for decision makers discussing these options to be informed about their possible economic impacts on an economy-wide scale.

Answering questions with such a level of complexity requires the use of quantitative models. In the field of industrial ecology several tools have been developed that can be used for systems analysis and design or for the evaluation of the environmental consequences of alternative technical and organizational options (e.g. life cycle assessment, substance flow analysis, and material flow analysis [MFA]). These tools are mainly rooted in natural sciences and engineering. Tools for evaluating or integrating economic indicators have recently been developed, e.g. economically extended MFA (Kytzia et al. 2004), but are still only rarely used (for an overview see Kytzia and Nathani 2004). Besides analyzing the microeconomic aspects of industrial ecology strategies it is also important to turn to the meso- and macroeconomic aspects.

Material flow models are usually restricted to a subsystem of the economy, which they cover in great detail. On the other hand they usually lack integration into the overall economic context. They require exogenous assumptions on future product or materials demand or relevant macroeconomic variables. The consequences of changed material flows on economic sectors outside the particular system boundaries and on the economy as a whole are not taken into account.

The integration into the overall economic context can be realized by a hybrid modeling approach, which links a material flow model with a meso- or macro-level economic model. Such an approach is presented in this chapter.

The existing hybrid approaches can be subdivided into two groups. In the first group, the material flow model is linked sequentially to an economic model (mostly an input-output model). Thus there is no feedback from the material flow model to the economic model. In the second group both models are mutually linked and interdependent.

With regard to the first group of models, several approaches have been proposed, which focus on the economy as a driver of materials consumption. Ayres (1995) presented a methodological approach linking a process-based material flow model with an economic input-output model, in which the activities included in the material flow model (such as resource extraction and basic industry processes) are excluded from the IO model. The latter's role is to generate a demand vector for certain goods to be delivered by the materials subsystem, whereas the manufacturing of these goods and the material flows induced (resource consumption, waste, emissions) are calculated in the material flow model. Similar approaches were presented, e.g. by Konijn et al. (1997) and Duchin and Lange (1998), with an application to plastics consumption and recycling.

Concerning the second group of modeling approaches, linking process chain models to economic models, there have been several applications in the field of energy policy modeling (see, e.g. James et al. (1986) for an early example, Zhang and Folmer (1998) for an overview). Applications to industrial ecology issues are not as widespread yet. Kandelaars (1999) linked a substance flow model with an applied general equilibrium (AGE) model. The aim was to simulate the economic consequences of regulatory levies on substances or products containing particular substances. The information from the substance flow model allows to determine the use of substances and the substance-based levy burdens in the economic sectors. With the AGE model the economic impacts of the levies (e.g. on sector output) are calculated, which in turn allows to determine new values for substance flows. Although this approach mutually links the two models, it represents a weak link in the sense that the respective structural model parameters are still independent.

Approaches with stronger links between structural parameters were presented by Mäenpää (1996) and Nathani (2003b). Mäenpää linked satellite material flow models to an econometric inter-industry model in order to evaluate the economic effects of changes in the sub-sectors. Nathani presented an approach for linking a material flow model with an economic input-output model and discussed in-depth the conceptual aspects of linking these two models. In the following the latter modeling system is presented in more detail.

The methodological framework of linking a material flow model with a dynamic input-output model is presented below. For the purpose of illustration, Empirical Application contains the application of this approach to the case of the paper cycle in Germany. Finally the benefits and limitations of the proposed approach are discussed and an outlook to further research is presented in the concluding section.

The Modeling Framework

In the following sections input-output and material flow models are introduced briefly before the linkage method is presented. The introduction is restricted to aspects necessary for understanding the model linkage. For further information the reader is referred to the respective handbook chapters.

Input-Output Models

Among macroeconomic models used for empirical research, input-output models have the highest level of sectoral detail and are thus especially useful for linking with a detailed material flow model. They are based on input-output tables, which disaggregate the (national or regional) economy into a number of economic sectors and describe the flows of goods between these sectors. The inputs and outputs of each sector are recorded in monetary units. The rows of the table display the outputs of each producing sector to other producing sectors and to the sectors of final demand (e.g. households, investment or export). The columns display the inputs of each producing sector, which are either intermediate inputs from producing sectors or primary inputs such as labor, capital depreciation or profits.

Several kinds of input-output models have been designed for different economic questions (see Miller and Blair [1985] for a good overview). This variety of models can be grouped into:

- Open and (partly) closed models
- Quantity and price models and
- Static and dynamic models

The linkage method described in this chapter makes use of two types of models: a dynamic input-output quantity model and a static price model.

Dynamic quantity models also exist in various specifications. In the following the dynamic input-output model MIS (Macroeconomic Information System IKARUS), which was used for the empirical application, is presented briefly. It has been developed as a macroeconomic driver for the German energy flow optimization model IKARUS (Pfaffenberger and Kemfert 1997). MIS is used for projecting future input-output tables of the German economy. In the model version used for the empirical application the base year is 1995 and the projection years 2005 and 2020. Production activities are aggregated to 27 sectors. The final demand sectors include private consumption, government consumption, investments and exports. Except for investment, final demand is projected exogenously. Since investments are calculated endogenously the basic equation for calculating output differs from the standard static IO model.

Sectoral output in the period t_1 is calculated as:

$$x(t_1) = (I - A(t_1))^{-1}(y(t_1) + v(t_1)) \tag{10.1}$$

with $x(t_1)$: vector of sectoral outputs in period t_1
I: identity matrix
$A(t_1)$: matrix of input coefficients in period t_1
$y(t_1)$: vector of exogenous final demand (excluding investment) in period t_1
$v(t_1)$: vector of investment in period t_1 = depreciation + net investment

For the endogenous calculation of investment the sectoral capital stock is integrated into the model. The increase of capital stock is tied to the increase of value added by sectoral capital coefficients.

Model calculations of output $x(t_1)$ in period t_1 are run iteratively, starting with preliminary values for investment. From the output values sectoral value added and the required capital stock are derived. Capital coefficients remain exogenous, but can change in time. Net investment is calculated with the assumption of linear growth of capital stock between the two time periods t_0 and t_1. Investment for capital

Table 10.1 Scheme of a Material Flow Table

Inputs	Outputs	Economic System				Natural system	
		Processes and activities within system boundaries	Exogenous use				
Economic system	Process products	Material and energy flows within system boundaries	Intermediate use	Final use	Total product output	– Air emissions – Water emissions – Solid wastes – Excess heat	Total material output
		Other inputs from processes within the economic system					
Natural system		Material inputs from the natural system – Soil – Water – Air					
		Total material inputs					

replacement is derived from capital depreciation. With the new calculated values for investment, a new calculation of $x(t_1)$ is started. The iterative calculation procedure stops when the deviation of results between two calculations is sufficiently small.

In the model MIS energy efficient technological change is integrated through factors for autonomous energy efficiency improvement and price dependencies of the energy input coefficients in the transaction matrix as well as through links with technology-based submodels.

The static open price model of input-output analysis is used to calculate the effects of primary input value changes on sectoral prices (Miller and Blair 1985). It is based on the identity that the price of a good is equal to the costs of the necessary intermediate goods plus the primary input values. Price effects can be calculated by assuming that cost changes are completely passed on as price changes and that demand functions are perfectly inelastic. Since in most cases these assumptions are not very realistic, the calculated price effects have to be understood as crude estimations.

Material Flow Models

Material flow (MF) analysis[2] can be seen as the analysis of a system of processes and activities interconnected by material and energy flows within defined system boundaries. The choice of the system and the definition of system boundaries depend on the objective of the analysis.[3] In the context of this research work the aim is:

- To analyze the upstream and downstream material and energy flows connected to a selected product or product group
- To study the effects of production alternatives or different concepts of delivering a product service on material and energy flows in a consistent manner, i.e. by including all the relevant interactions

Therefore in a cradle-to-grave approach the analyzed system covers all important processes including extraction of resources, various manufacturing steps for turning the resource inputs into final products, product use, waste disposal and recycling. In principal all processes and materials relevant to the objective of the analysis should be covered. Alternative production and disposal routes, including those that might be realized in the future, should be included too. Often time restrictions and data limitations will pose a limit on the complexity of the analyzed system. Therefore the transparent definition of system boundaries is of great importance. Furthermore if the analysis of material flows is restricted to a certain region, appropriate regional boundaries have to be defined.

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[2] The term material is used with a very broad meaning covering resource inputs, goods of different processing stages as well as wastes and emissions. To improve readability the term material flows is also used when material and energy flows are meant.

[3] For an overview of methods and applications see, e.g. Bringezu et al. (1997), ***cross reference to chapter on industrial ecology***.

Material flow models can be constructed as simulation or optimization models, as static or dynamic models. Here we will look at a static simulation model, since in the hybrid model system the dynamics will be provided by the input-output model. A simulation model was chosen so that soft factors such as institutional and regulatory developments or changes of consumer behavior could be taken into account.

In a material flow model each process or activity[4] is characterized by its inputs, outputs and a transfer function, which links inputs and outputs and can be linear or non-linear. In case of linear transfer functions the transfer coefficients, which are calculated for each input as input divided by total output, become important model parameters. Technical change of a process, e.g. improved energy efficiency or increased use of recycled materials can be described through changes of the transfer coefficients.

For the purpose of linking the material flow model with an input-output model it is convenient to represent the material flows of a time period in an input-output table. Following Baccini and Bader (1996) the table columns contain the process inputs and the rows show the process outputs. The table consists of three sub-matrices with the central transformation matrix containing material flows between the processes included in the system, a matrix on the right of the central matrix containing flows leaving the system boundaries and a matrix below the central matrix containing the input flows into the system. This description of a material flow system also bears similarities with the economic–ecologic models of Victor (1972) or Isard et al. (1968) as described in Miller and Blair (1985) and formulations of a physical input-output table (e.g. Stahmer et al. 1998).

Regarding the linkage with an input-output model the structure of the material flow table can be differentiated as follows (see Table 10.1):

- Processes are assumed to have one specific product or homogenous group of products as main output. In case of co-production it is assumed that a process can be split with an appropriate allocation of inputs and outputs. The aggregation level of processes or activities can be freely chosen according to the aim and aggregation level of the analysis.
- Process inputs are further subdivided into
  - Inputs from other processes within the system boundaries
  - Inputs from processes outside system boundaries, but within the economic system and
  - Non processed inputs from the natural system, e.g. natural resource inputs
- The following outputs are distinguished:
  - Outputs to processes within system boundaries
  - Outputs to economic sectors outside system boundaries (exogenous use), which should correspond as far as possible with the sectoral classification of the input-output table. These outputs can be further classified as outputs

[4] These two terms are used as synonyms in the following text.

for use in sectors of intermediate and of final demand (including exports, but excluding consumption processes within system boundaries)
– Outputs to the natural system, esp. air and water emissions, solid wastes or excess heat

For each process as well as the system as a whole the mass balance principle applies, which states that total material input must equal total material output plus net stock change. Even though in practice it often proves difficult to collect all input and output data because of data restrictions, this principle can still be used as a consistency criterion and for the estimation of missing data.[5] This description of a material flow table is incomplete as it only considers material and energy flows, but no stocks. This poses a drawback especially for investment and consumption of durable goods, where after a certain lifetime these goods will enter the material system again as waste.

The Hybrid Model

In this section the hybrid model, which links a dynamic IO model with a static material flow model, is presented. First some conceptual aspects of model linkage and the steps necessary for linking the two models are highlighted. Finally the use of the linked model system is described.[6]

Linking an IO Model with a Material Flow Model

The basic idea of the approach presented in the following is to create a mutually linked modeling system consisting of a dynamic input-output model and a static bottom-up material flow model, which is set up as a satellite model to the IO model. The latter covers in detail a subsystem of the economy (e.g. the iron/steel or the paper cycle) as a network of connected processes. The models are connected by soft links in order to account for their conceptual and structural differences. The dynamics of the modeling system is provided by the input-output model, which supplies exogenous demand information for future projection periods to the material flow model. In the latter several scenarios for meeting this demand can be simulated (e.g. a business-as-usual scenario and one or several material efficiency improvement scenarios), integrating assumptions about technological development, behavioral patterns or regulatory measures. The results show the new material flows in the subsystem for these scenarios. In order to calculate the economic impacts

[5] In this description of a material flow system it is possible that a row comprises values in different units. Since the table is not used for calculation, but only for the link to the IO model, this does not pose a problem.

[6] This section focuses on the main aspects. For details, e.g. equations, see Nathani (2003b).

on sectors outside the subsystem, the simulation results of the material flow model are fed back to the input output model and lead to the adjustment of selected variables and parameters, which reflects the changes in the subsystem. For each scenario the adjusted IO model is run. The structural and other economic effects related to the material efficiency strategies are indicated by comparing the different scenario results.

The modeling concept includes a mutual link between the two interdependent models. Accordingly two interfaces need to be defined. From the perspective of the material flow model the input interface contains the variables and parameters which for future projection periods are influenced by values of the IO model (e.g. exogenous demand for the 'core' products or materials driving the considered material flow system). The output interface contains variables and parameters of the material flow model which influence their associated values in the IO model. The data flow is established for each time period, for which the IO model generates an IO table (1995, 2005, 2020 in the model version used). The feedback of the material flow model results to the IO model technically is done as follows. The IO model MIS generates IO tables for each considered time period. Since the material flow model only partly covers the sectoral transactions in the IO model, the values of these tables are partly adjusted on the basis of the material flow model simulation results, and partly left unchanged. The models are calibrated for the base year 1995 to determine for each value of the IO table, to which share it is not influenced by the results of the material flow model and thus left unchanged in the projection.

For the calibration of the models as well as for the feedback of MF model results to the IO model certain conceptual differences between the two models have to be taken into account:

- First, the accounting units are different. The material flow model is set up in physical units, whereas the IO model transactions are recorded in monetary units.
- An important difference concerns the activity concepts. Whereas a MF model can cover production, consumption and waste management processes alike, the latter two are only partly considered in the IO model. In a material flow model any technically or otherwise definable unit process can be represented separately. By contrast an IO model usually is restricted to production processes with market(-able) outputs, which are recorded in the underlying statistical sources. Therefore production processes included in a material flow model are not necessarily part of a producing sector in an IO model (e.g. recycled pulp as an input for recycled paper manufacturing). These aspects are important for associating processes in the material flow model with economic sectors in the IO model.
- Another aspect of model compatibility concerns the description of activities, which differs too. In both models activities are described with their respective inputs and outputs, though on different levels of aggregation. In material flow models process inputs and outputs are recorded in physical units. An important requirement is to fulfill the material balance condition. Thus in most cases the range of inputs and outputs included is restricted to material and energy inputs, whereas service inputs are usually excluded (with the possible exception of transport services). In an input-output model the sectoral inputs and outputs are

recorded in monetary units. Here it is necessary that a similar 'monetary balance principle' is followed, which requires the sum of inputs and outputs in monetary units to be equal. Compared to a material flow model, the scope of inputs and outputs is wider since also services are included. It is narrower since only goods with a market value are considered.

- Furthermore in the input-output model MIS the capital requirements of each sector are also recorded. This is also outside the scope of the material flow model.

These conceptual differences make several steps necessary in order to transform the results of the material flow model and make them compatible with the IO model concept.

In a first step the material flows recorded in physical values need to be converted into monetary values. This requires multiplying the physical values with base year prices. Depending on the material and the underlying activity these prices can be positive (in the case of traded/marketed process outputs), zero (in the case of consumption activities or non-priced materials e.g. material outputs to the ecosphere) or negative (in the case of most waste materials delivered to waste management). Waste outputs with a negative value are reallocated as inputs to waste management services (with a positive value). The result of these calculations is a material flow table in monetary values. It still may contain rows and columns belonging to activities yielding non-marketable outputs, which have no equivalent in the IO table. Therefore the inputs and outputs of these processes have to be reallocated to processes with market outputs in an appropriate way (e.g. inputs and outputs of recycled pulp processing to paper manufacturing). Finally inputs, which have not been considered in the material flow model (e.g. services), value added components and capital requirements need to be added for each market oriented process. The resulting extended monetary material flow table – including an additional row with the capital requirements of processes – is shown in Table 10.2. Finally this table is transformed into a table with the – usually more aggregated – sectoral classification of the IO model. The transformation steps mentioned above can be performed by a series of matrix operations which are described in detail in Nathani (2003b).

Table 10.2 Scheme of an Extended Monetary Material Flow Table

	Production	Use	Waste management	External demand	Exports	Natural system outputs
Production	x	x	0	x	x	0
Use	0	0	0	0	0	0
Waste management	x	x	x	x	x	0
External inputs	x	x	x			
Other economic inputs	x		x			
Value added	x	0	x		0	
Primary natural system inputs	0	0	0			
Similar imports	x	0	x			
Capital requirements	x	0	x			

Calculation Steps with the Linked Modeling System

The aim of the model is to determine the economic impacts of a material efficiency strategy (or more generally of changed material flows) in a subsystem of the economy. In most cases this will make a comparison necessary between a reference scenario and one or several 'material efficiency' scenarios. For each scenario the calculation with the linked modeling system consists of the following major steps:

- A first run with the isolated, i.e. unlinked input-output model
- Determining the exogenous demand for the material flow model
- Simulations with the material flow model
- A feedback of the simulation results to the IO model by adjusting selected IO model variables and parameters and finally
- A new run with the adjusted IO model

These steps are presented in more detail in the following (see also Fig. 10.1).[7]

1. A first calculation with the unlinked IO model for the projection year is started. In the case of MIS the main exogenous inputs, which have to be specified, include growth rates of exogenous final demand by supply sector (excluding investment) between the base year and the projection year, import shares for each of the sector outputs in the projection year, the capital coefficients and the composition of sectoral capital stocks by supply sector.
2. Based on this calculation, the values of the IO variables controlling the input interface variables are used for deriving exogenous demand as an input to the material flow model. Since the IO data is usually more aggregated than the MF data, further specific information or assumptions (e.g. regarding product mix or efficiency of materials consumption) should be used to determine the exogenous demand. For the conversion of IO monetary units into physical units constant base year prices at the product level are used.
3. Exogenous demand is taken as a starting point for simulation runs with the material flow model. Scenario assumptions regarding technology diffusion, development of consumer behavior, product-mix, environmental regulation and adoption of various material efficiency strategies and their effects on the material and energy flows in the system can be consistently simulated in the framework of the material flow model.
4. After the model simulations a new material flow table for the projection year is available for each scenario. This is transformed into a new extended monetary MF table and aggregated to the IO sector classification for feedback to the IO model.
5. The IO table of the projection year is adjusted on the basis of the MF model results. Each IO value at least partly associated with the MF model output interface is calculated as a sum of two components. The part not covered remains

[7] For further details, e.g. equations see Nathani (2003b).

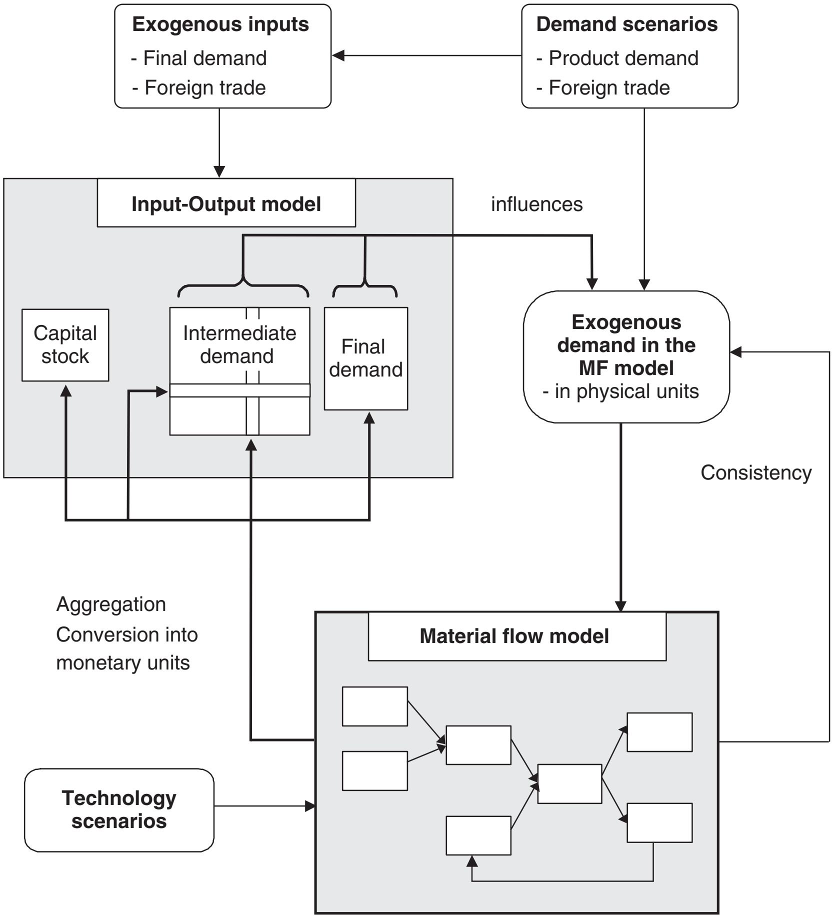

Fig. 10.1 Scheme of the Hybrid Model Link

unchanged, the covered part is replaced by the sum of the projected monetary values of the associated MF variables. Further adjustments reflecting sectoral shifts might be necessary in the IO model.

6. After adjustment the IO model is run again. The new results can influence the values of the input interface variables and thus the exogenous demand in the material flow model. This feedback effect has to be solved by iterative runs of the two models until changes of input interface values are smaller than a chosen threshold value.
7. The economic impacts (esp. on sectoral structure) of a material efficiency strategy are indicated by the differences between the results of the reference scenario and any other material efficiency scenario. Other aspects (e.g. employment) can also be taken into account in such an analysis by integrating the respective sectoral indicators.

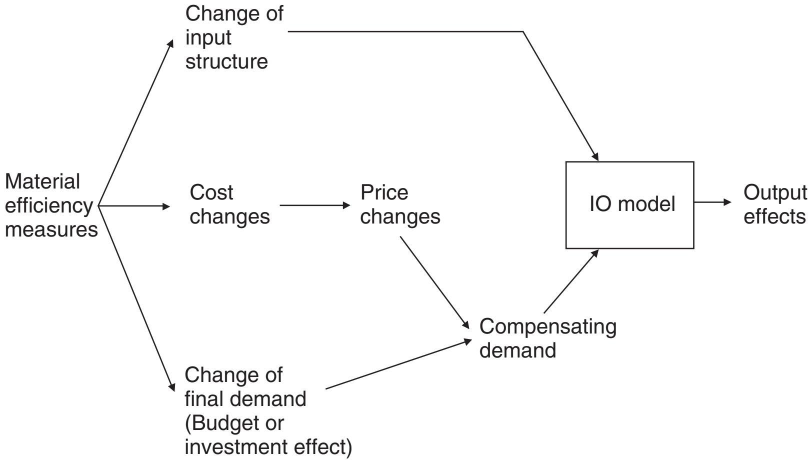

Fig. 10.2 Procedure for Estimating the Economic Effects of Material Efficiency Measures

Altogether the considered material efficiency measures can trigger four kinds of effects, which have to be captured in the input-output model (Fig. 10.2):

- Changes of input structure (first order structural effect)
- Changes of overall costs for the producing sectors
- Change of final demand expenditures, which can be termed as budget effects and
- Change of sectoral capital stock, which affects investment and thus final demand

These changes lead to further economic reactions, which can only partly be analyzed endogenously in an input-output framework. Especially cost changes and changes in final demand budget can have a variety of economic consequences, depending on market conditions, price elasticities, consumption priorities, etc. In this modeling framework they are estimated with subsequent simulations, after calculating the first order structural effects. Concerning the cost changes of the producing sectors, it is assumed that these generally are passed on as price changes throughout the economy, ultimately leading to price changes for final demand. This results in a changed purchasing power of the final demand sectors, which is assumed to lead to additional or less expenditures in these sectors. The price changes are calculated with the open static price model. Changed final demand expenditures are also assumed to result from budget or investment effects.

Regarding the commodities to which these compensating expenditures are directed, two different 'compensation' cases are distinguished to capture the spectrum of possible reactions. If we for example assume decreasing prices, then in the first case (named 'price driven compensation') savings from decreasing prices of a commodity are directed to the same commodity, implying a price elasticity of demand of approximately minus one. In the second case (named 'demand structure compensation') it is assumed that additional demand follows the average final demand structure of the particular projection year. With regard to price or budget effects in foreign countries and their possible flowback to the domestic economy these two cases also contain different assumptions, with the second case leading to a lower boundary for compensating demand. Thus the two cases differ regarding both extent as well as structure of compensating demand.

For the calculation of the cost and budget effects the additional demand estimated for the two compensation cases is added to final demand. Then a new calculation with the adjusted IO model provides the connected output effects.

Empirical Application

The empirical application of the linkage concept is presented with a case study of the German paper cycle as an energy and resource intensive material system. Paper is a material which still shows high growth rates. In Germany paper consumption in the last 30 years has grown stronger than the GDP. Even though paper recycling has reached a relatively high level, there still is a large potential for further improving material efficiency in the paper cycle. In order to analyze the economic effects of realizing these potentials, a material flow model of the paper cycle in Germany was set up with 1995 as base year. Projection years for calculations with the linked model system were 2005 and 2020.

Set Up of the Linked Model

Figure 10.3 contains a rough sketch of the paper cycle covering processes from forestry and industrial wood supply to production of pulp, of paper and paper products, consumption of paper products to their disposal resp. collection and processing of waste paper to recycled pulp. The implemented model has a higher level of detail. Six different paper grades and their flows to ten processes for use or further processing are differentiated, since the respective material efficiency improvement options and their realization potentials differ strongly. Stocks of long-living paper products have not been considered in the model due to their low relevance (7% of total paper consumption in 1995).

For each process the main inputs and outputs were included. Beside the main wood-based materials these are energy inputs, auxiliaries like process chemicals, fillers and pigments and transport services. Because of time restrictions and data limitations the scope of coverage had to be restricted. Special attention was paid to the processes of the paper industry since these dominate environmental pressure from the paper cycle. Since the main focus was placed on resource and energy use, the water use and water emission side was not included. Wastes were considered in so far as they can be used for recycling within the system or for energy recovery. Similar to the input-output model the analyzed system covers material and energy

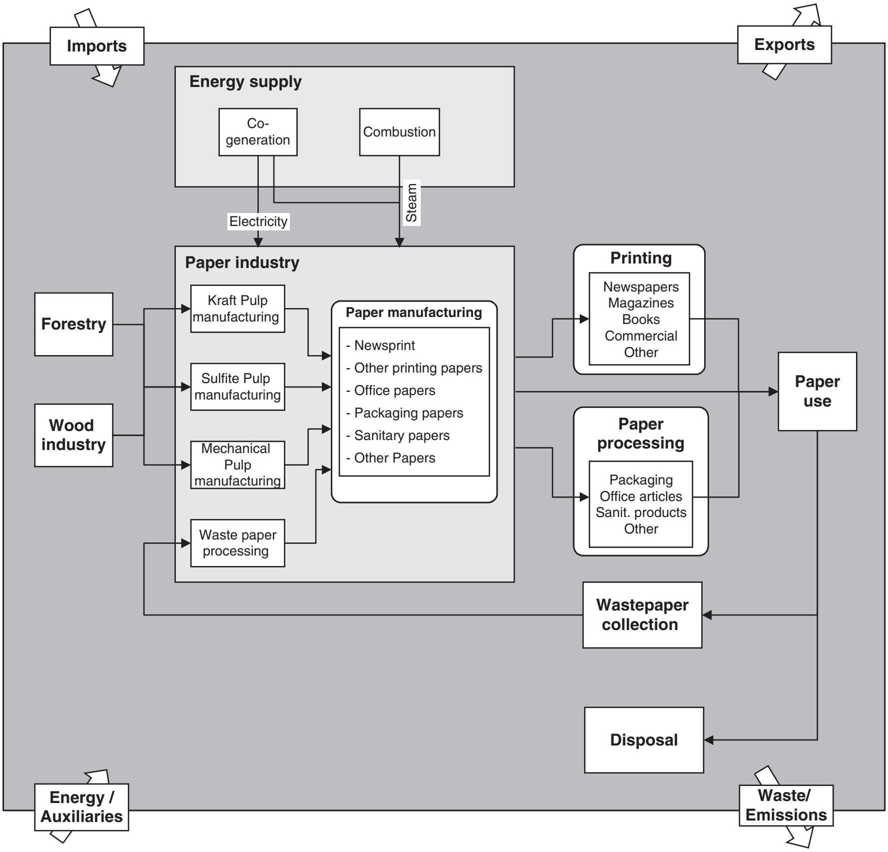

Fig. 10.3 Overview of the Paper Cycle as Represented in the Material Flow Model

flows within the national boundaries of Germany. However, on a product level imports and exports were taken into account.

The material flow model was implemented with the software 'Umberto', a professional software developed for material flow analysis (see Schmidt and Schorb (1995) for further information).

The main data sources for production, foreign trade, consumption and waste paper collection were official and industry statistics. Specific data concerning process inputs and outputs ware based on technology-specific data sources like process descriptions, life cycle inventories, material flow analyses of the paper chain or interviews with paper technology experts. Price information was mainly derived from production and foreign trade statistics, which record both mass and monetary units, and industry sources. In some cases export or import prices were used as estimates for domestic prices. In a last step monetary product values were calculated and aggregated to the IO sector level and finally harmonized with the corresponding values of the base year IO table.

In order to link the material flow model with the input-output model the following steps described in the Modeling Framework Section were carried out:

- Setting up a material flow table for the base year.
- Creating a price matrix and a monetary material flow table. The process inputs not covered in the material flow model (e.g. services; value added) were allocated according to the average ratio of the corresponding IO sector. The processes' capital stock data was estimated by using literature data.
- Defining the input and output interfaces. The six paper grades were chosen as core products and their domestic consumption as the characteristic demand driving the material flow system.
- Calibrating the models for the base year.

Table 10.3 contains an overview of the IO sectors partly or completely covered by the material flow model. The main focus lies on the inputs and outputs of the paper industry. In total, 80% of the intermediate inputs into paper industry in monetary terms are covered by the material flow model. The electricity and heat sector is covered partly, with regard to electricity and steam production in the paper industry. Waste paper collection as part of the service sector is also included. Paper products are not used to directly adjust IO data but only in the context of the material flow model.

Scenarios of the Future Development of the Paper Cycle in Germany

Several strategies for reducing environmental impacts from activities in the paper cycle were considered. Apart from pure material efficiency measures, options for improving energy efficiency were also taken into account in order to calculate the energy saving potential of a material efficiency strategy. The considered measures are:

- Increasing waste paper recycling and use of recycled pulp in paper manufacturing
- Increasing the efficiency of paper use in the areas of packaging design, office and home uses
- Reducing specific paper weight in selected paper products, e.g. printing paper
- Realizing potentials of information and communication technology (ICT) for substituting paper products, e.g. e-mail, dissemination of information via internet, CD-ROMs, etc.
- Improving energy efficiency of pulp and paper manufacturing and
- Improving energy supply in the paper industry by expanding use of combined heat and power plants and by substitution of energy carriers

Regarding the development of the paper cycle to the year 2020, one business-as-usual (BAU) scenario and two material efficiency scenarios were generated, reflecting different combinations of the above mentioned measures and different levels

Table 10.3 Overview of the IO Values Covered by the Material Flow Model

to From	Electricity/heat	Paper industry	Paper process	Printing sector	Waste-paper trade	Other intermed. demand	Final demand
Agriculture/forestry		(x)					
Electricity/heat	(x)	x					
Colar sector	(x)						
Natural gas supply	(x)	x					
Chemical industry		(x)					
Refineries	(x)	x					
Nonmetallic minerals		x					
Paper industry	x	x	x	x		x	x
Other industry		(x)					
Waste paper trade		x					x
Services		(x)					(x)
Transport		(x)					
Gross value added	(x)	x			x		
Similar imports		x			x		
Gross output	(x)	x			x		

x: IO value completely covered by MF model.
(x): IO value partly covered by MF model.

of realization. This chapter will focus on the BAU scenario and the second, more ambitious material efficiency scenario.

Furthermore for the unlinked model run a baseline scenario was defined, specifying assumptions for the exogenous variables of the IO model such as the development of exogenous final demand (excluding investment) as well as of foreign trade. For the projection of final demand for wood pulp, paper and paper products micro-level information such as existing projections or market research analyses was used. Technological change resulting in a changed input matrix was not considered. The possibilities of MIS to consider autonomous and price-induced change of energy input coefficients were inactivated just as in all other scenario calculations in order to isolate the effects of the analyzed material efficiency improvement measures.

The business-as-usual (BAU) scenario accounts for developments, which are likely to happen without any further political interventions. Assumptions were made regarding process improvement and diffusion of new technologies, changes of product-mix, trends in energy demand and energy supply and the level of paper recycling. The output level of the paper industry as a whole was taken from the baseline calculation and cross-checked with specific projections by paper industry experts, which also provided the breakdown by paper grade in the future periods. The effects of these changes on the paper cycle were simulated with the material flow model. The BAU case thus was the first case calculated by linking the IO model and the material flow model.

The scenario "sustainable paper cycle (SPC)" assumes a high realization of material efficiency potential. This involves all measures described above, for which improvement ratios were assumed, based on existing bottom-up information (for further details see Nathani [2003a]). In comparison with the BAU scenario, these measures altogether lead to a decline of paper consumption by approximately 20% in 2020, depending on the respective paper grades. The basis for this estimation were several studies analyzing possibilities for reducing paper consumption and the potential of IC technologies for substituting paper products (Abramowitz and Mattoon 1999; BCG 1999; Hekkert et al. 2002; Hoppe and Baumgarten 1997; IIED 1995; Obersteiner and Nilsson 2000; Robins and Roberts 1996; Romm 1999). Yet the estimation is subject to rather high uncertainties. It was further assumed that similar reductions would be realized in other industrialized countries.

As a result of the baseline scenario assumptions MIS calculated a growth rate for German GDP of 2.0% p.a. between 1995 and 2005 and 1.8% p.a. between 2005 and 2020. The aggregated exogenous demand for paper is assumed to grow in line with GDP, though with different growth rates for the different paper grades. Import quotas on the product level were assumed to remain constant throughout the projection period.

Figure 10.4 shows the development of paper production and consumption in Germany in the business-as-usual scenario and in the scenario "sustainable paper cycle". In the BAU case paper consumption increases from 18 million tons in 2000 to 25 million tons in 2020. In the SPC-scenario consumption lies approximately 20% below that value at around 20 million tons. Since production is assumed to increase faster than consumption, in both scenarios Germany would turn from a net importer of paper to a net exporter between 2005 and 2010.

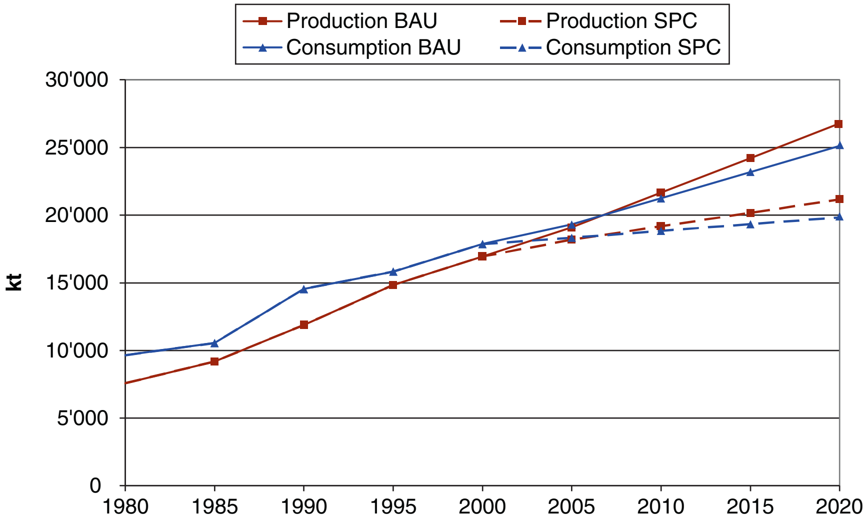

Fig. 10.4 Development of Paper Production and Consumption in Germany Between 1980 and 2020 (VdP, 2001; own assumptions)

Results of the Model Calculations

The discussion of the simulation results will concentrate on the differences between the BAU and the SPC projection for the year 2020. For each scenario the results can be subdivided into three parts:

- The results of the simulation with the material flow model, confined to the subsystem of the paper cycle
- The adjustment of the affected variables and parameters of the IO model and
- The final results of the calculations with the IO model

Regarding the first part, the results shall be only summarized briefly. The scenario assumptions lead to various changes of material and energy flows in the paper cycle. They affect the output and mix of paper grades, fiber and other input demand for paper production, energy consumption and transport service demand, waste paper collection and waste management. By assumption the demand for paper products is also reduced significantly. The results show that a stagnation or slight reduction of resource and energy use in the paper cycle can only be achieved if growth of paper consumption can be restricted to the level of the SPC scenario.

These results directly affect three sectors in the IO model, the paper industry, the electricity sector and the services sector, which comprises waste paper collection and trade. The latter two sectors experience minor changes. With regard to the paper industry domestic output and thus supplies to the other sectors of the economy are considerably lower in the SPC scenario. Monetary output declines from about €21.3 billion in the BAU scenario to €16.9 billion in the SPC scenario. Imports of

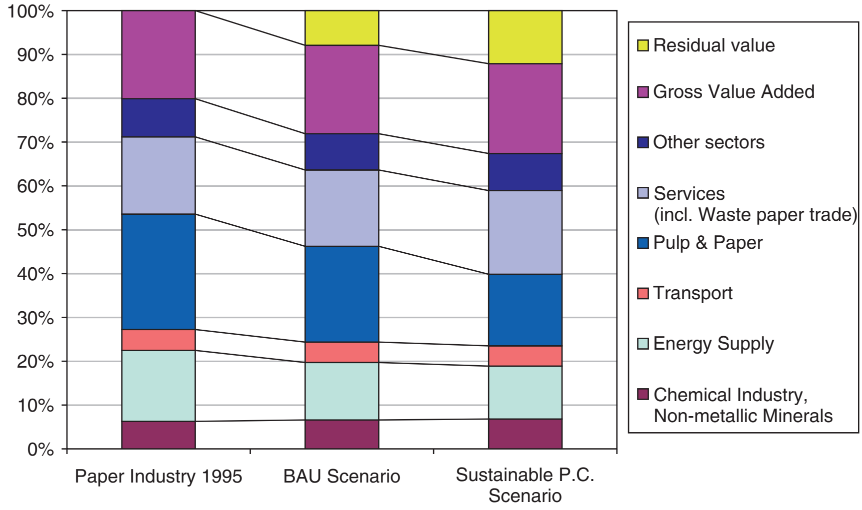

Fig. 10.5 Input Structure of the Paper Industry in 2020 Compared to 1995

pulp and paper also decrease from €12.7 to €9.1 billion. The input structure of the paper industry also changes considerably, reflecting lower energy consumption and slightly lower transport services demand and especially the shift from wood and imported kraft pulp to waste paper (Fig. 10.5). The latter shift can be seen as a decrease of pulp inputs and an increase of service inputs (waste paper collection). Since the use of waste paper is cheaper, the overall costs of the paper industry decrease. Compared to the baseline scenario, in the SPC scenario specific manufacturing costs are approximately 12% lower. The gap between output and inputs is depicted as "residual value" in Fig. 10.5. To a certain extent this can be interpreted as cost savings, although the cost structure for the two scenarios are not completely comparable, since product mix and quality are different. Paper with a higher content of recycled pulp has a different quality than paper with a higher content of fresh pulp.

The reduced consumption of paper and paper products as well as the increasing demand for ICT products and services have various consequences for other sectors, which are directly implemented in the adapted IO model (see Table 10.4). The outputs of the paper processing and especially the printing sector decrease. This decrease is translated into a decreasing supply of these sectors to the other sectors of the economy. The declining demand for printing products is assumed to be offset by an increasing demand for ICT products and especially ICT and media services. Because of lacking data it was not possible to perform an in-depth analysis regarding cost and details of this substitution process and the resulting new demand. Based on the idea, that in order to be accepted by the customers, the new products and services would have to be cost-competitive with paper products, it was assumed that their total costs equal the total costs of the substituted paper products including transport and retail margins. On balance the material efficiency strategy leads to substantial cost reductions for the producing sectors and the households and to reduced exports.

Table 10.4 Change of Supplies to Intermediate Demand (Without Paper Industry) and to Exogenous Final Demand Sectors (Difference Between SPC and BAU Scenario)

Supplying sector	Intermediate demand (w/o paper industry) (Mio. €)	Households (Mio. €)	Exports (Mio. €)
Paper industry	−1,950	−69	−2,593
Paper processing	−635	−341	−399
Printing sector	−11,325	−52	−535
Transport sectors	−479	−368	
Wholesale (services)	−412		−464
Other sectors	−100	343	
(ICT) services	12,079		
Cost balance	−2,822		
Final demand balance		−487	−3,992

The impact on capital stock and thus on investments are negligible. The cost savings lead to price reductions, which are fully compensated by additional demand, just as are the savings in households. The reduced exports are only partly compensated, depending on the compensation case. In the case 'price driven compensation' a higher share of export decline is compensated by additional demand than in the case "demand structure compensation".

Regarding the results of the calculations with the adjusted IO-model, these are depicted as differences between the "sustainable paper cycle" scenario and the business-as-usual scenario in order to highlight the economic effects of the material efficiency measures taken additionally in the SPC scenario.

Figure 10.6 shows the impact on sectoral output resp. imports without considering the compensation mechanisms (first order structural effect). Domestic output of the printing sector and the paper industry as well as pulp and paper imports decrease considerably. On the other hand the services sector, including the ICT services, is the only gaining sector. The other sectors are also affected negatively. Overall domestic output decreases by nearly €13 billion, whereas imports decrease by about €5 billion.

The compensation mechanisms partly offset the overall negative output effects (domestic output and imports, see Fig. 10.7). Yet, in both compensation cases the paper oriented sectors stay negatively affected, though less in the second case. A multitude of sectors gains from a higher final demand, especially the service sectors.

Despite compensation the total impact is still surprisingly negative, with a loss of output between €6.5 and €11 billion. Domestic output decreases between approximately €3.5 and €7 billion, whereas imports are reduced by between €3.5 and €4.3 billion.

This negative overall effect is due to the situation of Germany as a net exporter of paper in 2020. One important scenario assumption was that a material efficiency strategy would also be followed in the other industrialized countries. Since this

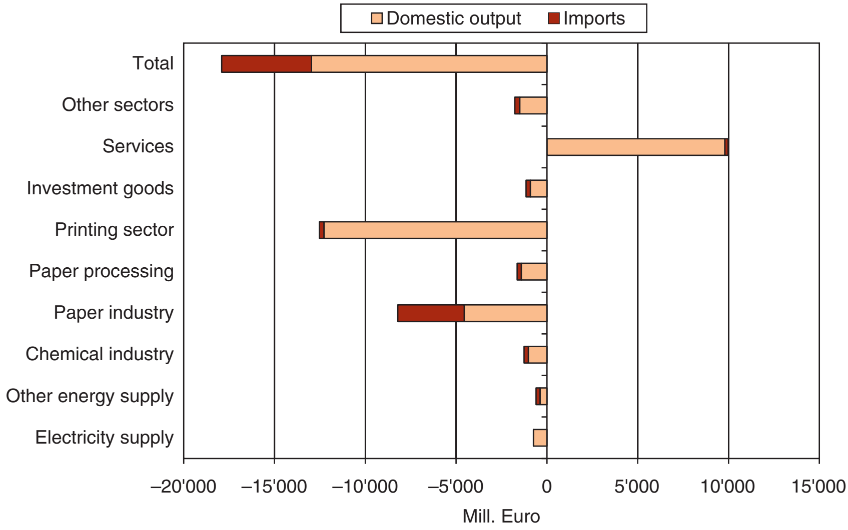

Fig. 10.6 Change of Domestic Output and Imports in the SPC Scenario in 2020

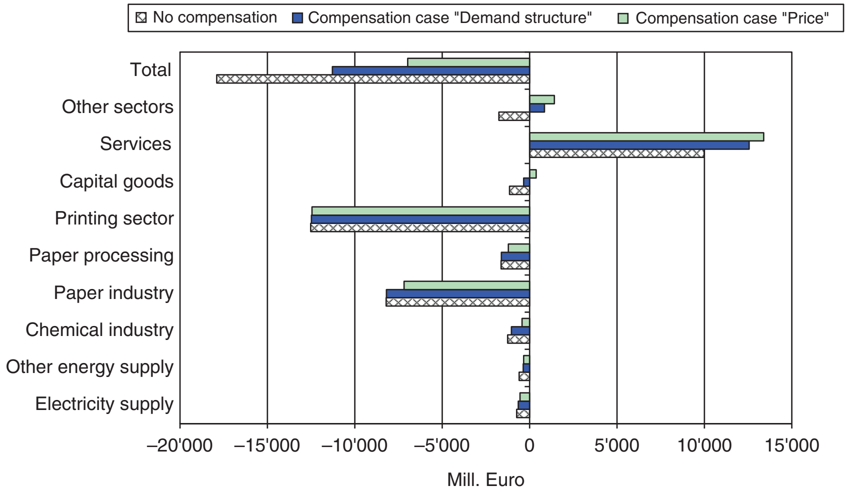

Fig. 10.7 Output Effects in the SPC Scenario in 2020 Including Compensating Effects

strategy on balance causes a shift from paper based products to services, which are assumed to be mainly provided by domestic suppliers, the German economy loses with its net paper exports, whereas the compensation for this decline mainly takes place in the foreign countries. This results in an overall negative output effect for the German economy.

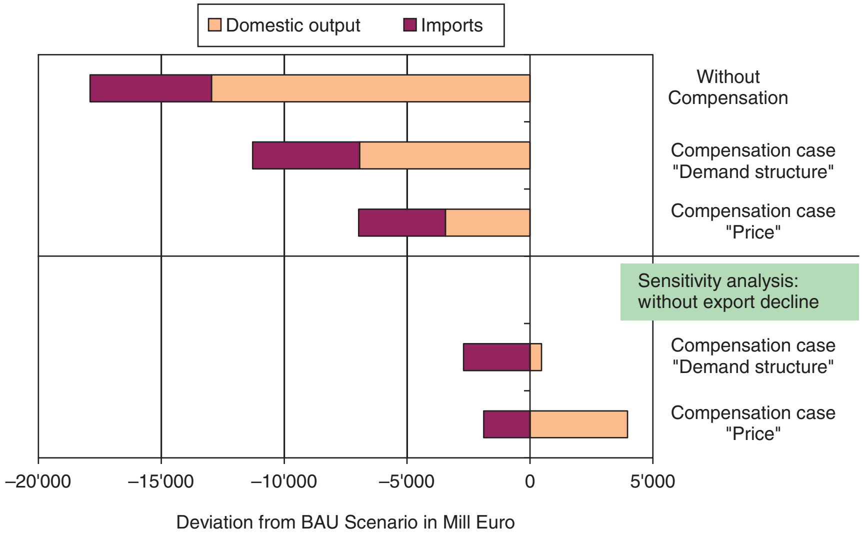

Fig. 10.8 Output Effects in a Sensitivity Analysis Assuming Unchanged Exports of Paper Based Products

This effect can be clarified by a sensitivity analysis, in which the exports of the three paper based sectors remain unchanged at the level of the business-as-usual scenario. In this case final demand in 2020 would increase by about €3.5 billion. The total output effect would lie between a decrease by €2.2 billion and an increase by €2 billion, compared to the BAU scenario and depending on the compensation case. Yet in both cases domestic output increases, whereas only the imports are negatively affected (Fig. 10.8).

A similar analysis was performed for employment, assuming a linear relationship between sectoral output and employment, though with higher sectoral labor productivities in 2020. The results show a significant job loss of about 44,000 employees as the first order structural effect, whereas compensation results in a minor job decrease of about 2,000 employees resp. a moderate job gain of about 17,000 employees depending on the compensation case (Fig. 10.9). Assuming unchanged paper exports the job effect is reversed to a significant positive effect of between 37,000 and 58,000 employees. These results show that the labor intensity is higher in the winning sectors than in the losing sectors.

This kind of analysis was also extended to energy demand as an environmental indicator, again by assuming a linear relationship between sectoral output and energy demand, though with lower energy intensities for 2020. The results show a significant reduction of energy demand by about 70–80 PJ already in the business-as-usual scenario (compared to the baseline), mainly due to increased energy efficiency in the pulp and paper industry. In the 'sustainable paper cycle' scenario the energy demand gap is further reduced to between 90 and 110 PJ, mainly caused by lower output of paper and paper products.

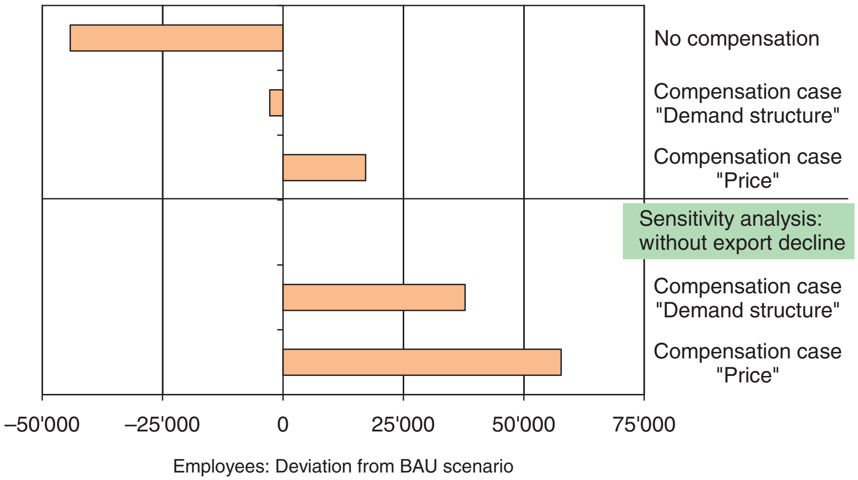

Fig. 10.9 Employment Effects in the SPC Scenario in 2020

Discussion and Outlook

Since material efficiency strategies aim at a redesign of complete process chains or networks it can be assumed that a realization on a large scale will have an impact on the economy as a whole, especially on sectoral structural change. Therefore decision making with regard to these strategies should – apart from the environmental impacts – also take the possible economic impacts into account. In this chapter a methodological approach for analyzing these economic impacts was presented. It was empirically applied to a case study of the German paper cycle.

This so-called hybrid approach implies linking a dynamic economic input-output model with a static technology-based material flow model. The two models are mutually linked and influence each other. Thus the material flow model, which describes a subsystem of the economy with high technological detail, can consistently be embedded into the overall economic context. On one hand its exogenous demand is influenced by the development of the economy, on the other hand changes within the subsystem are fed back to the input-output model.

The hybrid approach combines the advantages of the two isolated models and offsets some of their limitations. The advantages of the presented linkage can be summarized as follows:

- The material flow model allows to catch the complexity of a process network integrating production, consumption and waste management (life cycle approach) and offers a consistent framework for scenario generation with respect to material efficiency measures. Thus the specificity of material and product systems regarding improvement options and realization potentials can be represented in an adequate way. Aspects of technical change or changing consumption patterns can be considered.

- Compared to the usual restriction of material flow models to physical units, the consideration of monetary values allows to show the economic consequences of measures for the involved actors. Apart from direct structural effects, cost and budget effects can also be identified by subsequent simulations with the IO model.
- Technical and intrasectoral structural change, which is a weakness of the IO model, can be represented in the material flow model subsystem by using scenario techniques.

Yet, outside the boundaries of the material flow model this weakness persists. Furthermore the applied input-output model MIS is limited in its representation of some macroeconomic interactions (e.g. explaining the relation between value added and final demand or trade relations). Partly these limitations can be offset by subsequent simulations as proposed in Modeling Framework. In most IO models as in the model MIS, representation of waste management activities is rather inadequate, mainly owing to lack of data for these sectors. For the analysis of economic–ecological interdependencies with the linked model system, the use of extended IO models, which take resource inputs and waste management into account, would be beneficial.

Regarding possible further research steps, other material and product systems could be studied, allowing for the bottom-up analysis of interactions between different subsystems (e.g. competition between different materials). With more complex products (e.g. cars), high-level recycling strategies like product remanufacturing or strategies for intensifying product use could be considered. The analysis of long-living products would also require further methodological developments of the hybrid approach by introducing a dynamic material flow model. Especially establishing consistency between a dynamic economic model and a dynamic material flow model would be challenging. Linking material flow models with other types of economic models (e.g. computable general equilibrium models) might also produce interesting insights.

In the empirical application employment as a social indicator was introduced additionally to economic indicators. This could be extended by indicators describing the quality of work (qualification aspects, extent of shift or weekend work etc.) and by environmental indicators, thus allowing to evaluate the sustainability of a material efficiency strategy – or of industrial ecology related strategies in general – with a methodologically consistent tool. Altogether the empirical application to other material and product systems as well as the further methodological development should enhance our understanding of the impacts of strategies that lead to a more material efficient economy.

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