Research Memorandum

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STREAM:

Substance Throughput Related to Economic Activity Model
A partial equilibrium model for material flows in the economy

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1. Introduction

Environmental degradation as a consequence of industrial development is one of the pressing problems facing society today. The problem achieved the headline status in the mid-eighties when it became clear that *end-of-pipe* techniques, such as desulfurisation, catalytic convectors and electrostatic precipitation, were insufficient to solve environmental problems such as acidification, eutrophication, ozone depletion and especially greenhouse warming. The notion of *sustainable development* emerged [Brundtland, 1987] reflecting the recognition that the environment is an essential factor of production and a principal source of human welfare. It also became obvious that a substantial change of production methods as well as consumption patterns were required to achieve sustainable development.

Environmental pressure arises primarily from the extraction, production, use and disposal of materials. A strong increase of material productivity is therefore paramount to meet ecological sustainability. Halving resource use is generally regarded as an imperative condition. The *factor four* hypothesis [Weizsäcker, 1997] suggests that this condition can be met economically by attainable technical progress even when the economic activity level doubles. However, in the light of historical trends, it is not evident what mechanism should trigger this *industrial revolution* and what policy can advance this transformation.

The search for sustainability stimulated the development of methods to analyse the relations between material flows and economic activity and to design policy instruments that raise material productivity. Most methods or models to analyse material flows [Kandelaars, 1996][Bergh van den, 1998] are essentially descriptive or technically oriented. Examples are Material Flow Analysis, Input-Output Analysis, Life Cycle Assessment, Material-Product Chain Analysis and Bottom-Up approaches.

Although these models can be very informative in search for sustainable development, they allow misleading conclusions by lack of important economic mechanisms, spatial scales, dynamics and generality. The real world often reacts in another way than these models predict. These observed differences are labelled as *efficiency gap*, *rebound effect* and *environmental leakage*. The most neglected economic aspect in these models is that the introduction of resource saving technologies changes relative scarcity of many other goods and therefore the prices and demand for these goods. When these factors are taken into account, the overall environmental impact of such a technology can even be negative. Moreover, the price changes will also affect the comparative advantage for specific production activities in countries or regions and consequently induce a reallocation of economic activity and their emissions.

In order to analyse the role of economic mechanisms in environmental problems related to material flows, CPB's Energy and Raw Materials unit has developed the model STREAM[1], in cooperation with RIVM, the National Institute for Public Health and the Environment. STREAM describes the key dynamics, factors and parameters that determine material extraction, production, use, recycling and disposal, at a macro economic level and at different spatial scales. The model also provides a consistent framework for long-term[2] *scenario analysis* and rational understanding of future demand for and supply of natural resources. Moreover, it can be used for analysing the effects of *policy instruments* on material flows, such as taxes and regulation, on the supply and demand side of the material markets.

The model is of the well-known *equilibrium* type: consumers and producers are balanced by prices to the scarcity conditions on the markets. In fact it is a *partial* equilibrium model that only considers the material markets. This limits the size of the model but also its scope. Therefore, only the direct effects on the material markets of a certain policy can be analysed.

The model can also be characterised as a *Material-Product-Chain* model at the macro economic level. It is physically as well as macro economic oriented and therefore appropriate for *integrated assessment*.

The model is applied as an *interlinking model* between the macro economic models of CPB and the environmental models of RIVM. The physical output of the model also serves as input for NEMO, CPB's energy demand model. The model is defined on different spatial scales to analyse cross-boundary material flows and provides information about import prices of raw, primary and secondary materials for the Dutch economy.

The remainder of this study consists of four chapters. Chapter 2 presents the conceptual framework of the model. Chapter 3 elaborates the demand and supply equations in the model and discusses the related predominant themes in the field of material analysis. Chapter 4 illustrates the application of the model as an instrument for scenario and policy analysis. The main conclusions of this memorandum are summarised in chapter 5.

[1] STREAM is an acronym for: Substance Throughput Related to Economic Activity Model. This acronym is invented by Jan van Dam (RIVM)

[2] Long-term means here: for the next 25 years.

2. Framework

This chapter discusses the conceptual framework of STREAM: the application of the metabolic principle in the analysis of economic activity. Within that framework, it indicates: the relevant economic actors in the material product chain at the macro economic level, the related material and financial flows, and the market mechanism behind it. Moreover, it addresses the spatial dimension of material flows and the related environmental problems. This chapter rounds off with defining the scope of the model and its linkage between the macro economic and physically oriented models of CPB and RIVM.

2.1 Industrial Metabolism

The principal reason that the environment has been neglected as an essential factor of production is because many of its services, which are used as intake or outlet for consumption or production activities, are largely unpaid. Because they are unpaid, the economist perceived them as *external* effects.

To bridge the gap between macro economic analysis and environmental issues we need a concept that integrates economic activities and environmental services. *Industrial metabolism* [Ayres, 1994] is such a concept defined as the integrated collection of physical processes that convert raw materials and energy, plus labour, into finished products and wastes. This concept uses a compelling analogy to the *natural metabolism* of living organisms, that convert a nutrients and energy by physical or chemical processes into useful products for maintenance and growth, and into excrements which are used as nutrients by other life-forms. The major difference between the natural and the industrial metabolism is that the material (nutrients) cycles of the natural system are *closed* while the material cycles in the industrial system are basically *open*, exhausting natural resources and expanding waste dumps.

Physical processes are related to economic activities and the underlying decisions of their representative actors. The conceptual model distinguishes six actors/activities that are relevant from an economic and environmental point of view:

- *Mining industries*, that extract raw materials by disclosing geochemical reservoirs in the earth's crust. For each ton of raw material a multiple of tons overburden has to be removed at the costs of large quantities of water, energy, emissions of toxic substances and sulphur and loss of natural habitats. The raw materials are shipped all over the world to the basic industries.

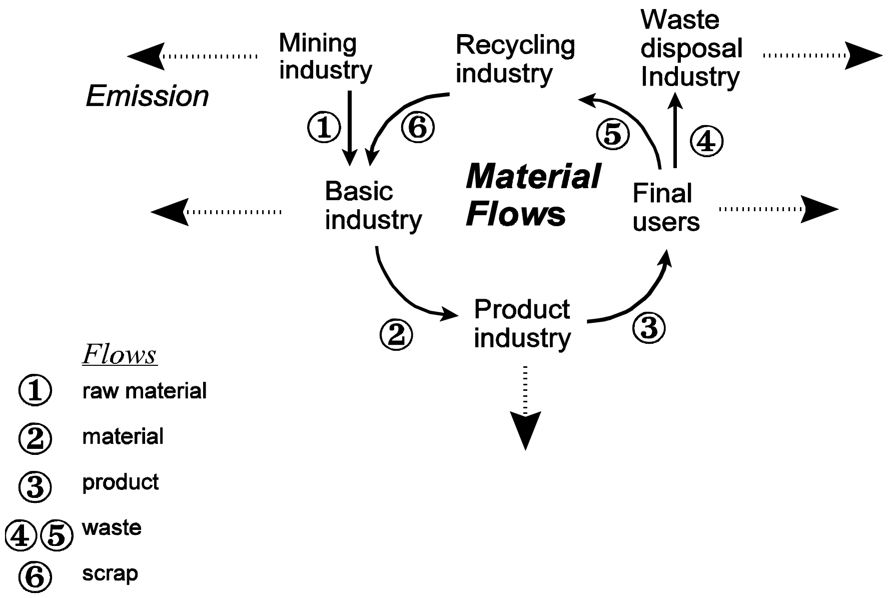
- *Basic industries* that refine raw materials and produce basic products such as steel, aluminium and plastics. They use about 65% of all energy in manufacturing and they are responsible for the bulk (50% to 80%) of all the emissions of toxic substances [Mannaerts, 1993].
- *Product industries*, that use a variety of materials to construct or assemble finished products. Most of the value (85% on average) of these products is added in this production stage with help of large quantities of labour and capital.
- *Final users* of finished products, who are also the suppliers of labour and capital. They receive compensation/income for their services, by which they finance their expenditures. The income level and relative product prices determine the composition of products that are bought by the final users. Backward linkages to the producers of these products also set the levels of material flows in the economy.
- *Waste disposal industries*, that take care of the finished products after consumption by collecting and incinerating or dumping waste. *Waste disposal* is characterised as *clean up* activity.
- *Recycling industries*, that collect and recover some materials, such as iron, aluminium, lead, paper and glass from waste products. Recycling is primarily limited to bulky homogenous products. The collection and recovery costs of these products are relatively low because of economies of scale. The revenues consist of saved inputs for material production, mainly energy and capital. A favourable side-effect is that material recycling mostly raises less environmental problems than production from virgin materials.

2.2 Material and financial flows

Figure 2.1 shows the above mentioned economic actors/activities in the framework and the material flows in-between (solid arrows) the actors. It depicts a *Material-Product-Chain* of subsequently linked material flows in different states: *raw, primary, product, waste and secondary*. Although recycling can take place, the material cycles in the economy are basically open. Large quantities of raw materials are added by the mining industry and escape the material cycle for the most part as emissions or waste (dotted arrows).

The framework also applies the *Material Balance principle* to the distinct economic activities: material input is material output plus material waste. The (multi-)material balance provides insight into the interrelationship between material flows and/or stocks and the related environmental problems.

Figure 2.1 Material Flows and Economic Activity



The special qualities of materials are essential in satisfying human needs such as for food, health, shelter, communication and transport. The qualities must be derived from minerals and then embodied into hundreds of thousands of different products. A variety of sequential manufacturing processes transform raw materials into useful products and contribute largely to the economic value of these products but also produce undesirable emissions especially in the basic industries. The *value added* or *net production* generated in these processes is transferred as an income to the suppliers of labour and capital in exchange for their services rendered. Next, this income is spent by the final users to the aforementioned useful products. The process of generating and spending income is the core of the economic process and together with the product prices a predominant factor in the determination of the volume and composition of the material flows. After consumption, the depreciated products enter the waste flow to be disposed or to be recycled and reused in the economic process. Both options may induce considerable environmental pollution. The dissipation of toxic substances from waste dumps frequently contaminates the local environment. And the recycling industry generally recovers only a part of the waste input and leaves many non-recoverable substances behind.

2.3 Economic choice, markets and institutions

The material flows between the economic actors in the model framework are determined by market forces and institutional behaviour. Market forces reflect private needs and preferences and the availability of privately owned resources. The price mechanism is the main device available in the economy to coordinate these forces. They encourage *efficient use* of resources which have to be paid for. However, economic actors also seek to *externalise* the costs of economic activities by turning them into social costs [Daly, 1991]. This implies that the market economy cannot attain an overall (social) state of efficiency on its own. However, institutions can redress this *market failure* by policy instruments, such as taxation and regulation. Institutions can also add new markets to the economy, for instance markets for pollution rights. In the model institutional behaviour is exogenous. It focusses on the market forces and the way material markets react on specific institutional behaviour.

Market forces, the forces of supply and demand, follow in a free competitive economy from economic choice. Final users can decide how to spend their income on different products and they can separate their refuse or leave it to the dustcart. Waste and recycling industry can incinerate refuse or bring it to landfills or recover the materials. Product industry can choose between different materials to assemble their products. Basic industry can switch from raw materials to scrap as material input. Industries can select technologies that are more or less energy-, labour- or capital-efficient. In the model choices are based on *cost-minimizing* behaviour of the economic actors, given the market prices for *labour, capital, fuels, electricity and materials.* The outcome of this optimising process can be depicted by *demand and supply* relations. Supply and demand forces seek an equilibrium solution that determines simultaneously the market prices and material flows. *Equilibrium* on a market exists if demand equals supply. This will happen if the market price equals the equilibrium price.

Market prices and material flows may adjust because of changes in all other markets. For example, a change in the bauxite market will subsequently affect the bauxite price, the aluminium cost price, steel demand, steel scrap demand and the price of steel scrap. Consequently, environmental policy aimed at changing production methods or consumption patterns will not just affect one market but also pass through to other markets and have an impact on all economic activities and their related material flows and emissions.

2.4 Authorisation levels and spatial scales

A thorough analysis of the relationship between material flows and economic activity should examine this relationship at three levels of authorisation and/or social organisation:

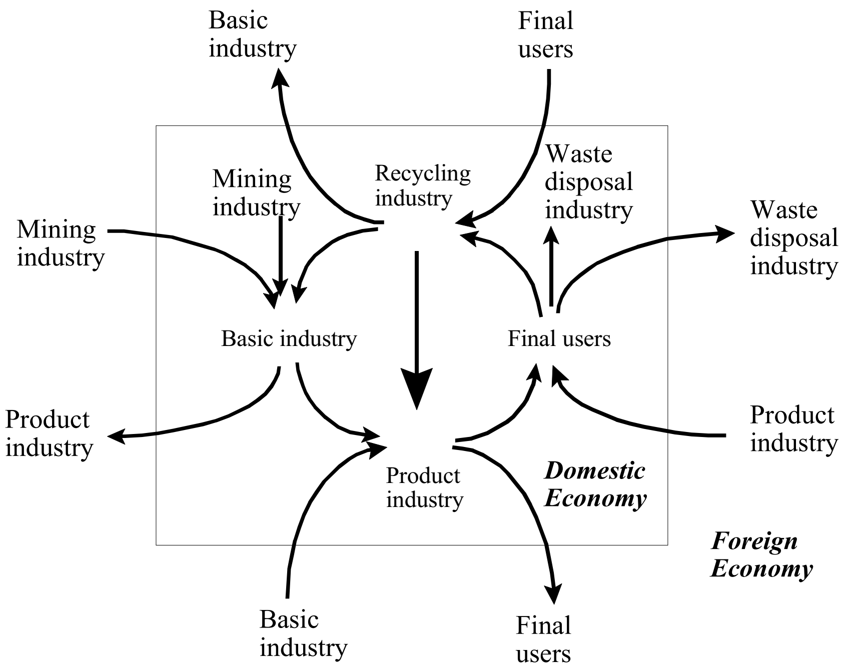
- *The economic actor*, who makes decentralised choices on production and consumption of materials.
- *The national economy*, with its specific national organisation of input and output markets, lifestyle, infrastructure, institutions and government policy.
- *The international economy*, in which the market prices for most raw, primary and secondary materials are set and international organisations exert a coordinating role.

These authorisation levels also have an important spatial dimension. Different national economic conditions determine the international allocation of polluting activities and the dimension and scale of the cross-boundary material flows. These cross-boundary flows originate in activities that may leave their *ecological footprint* in another country or region. Ecological policy should take into account these footprints. Indeed, due to the very open nature of the Dutch economy, these external effects are substantial. This calls for an analytical framework that accounts for international material flows. Figure 2.2 shows such a framework.

The complexity of the model increases substantially compared to figure 2.1. The economic activities and material flows double. Every actor can obtain inputs and sell output on the domestic market as well as the foreign market. The actual choice depends on cost differences that originate in differences between countries in terms of wages, interest rates, resource availability, infrastructure, institutions and government policy.

Although figure 2.2 is not very informative from a scientific point of view, it is a fruitful guide for policy decision makers in selecting their instruments. Every measure imposed upon an economic actor induces a revision of choices by the actor and thereby substitution between materials and shifts in origin and destination of material flows. The figure also shows that backward demand links (flows) and forward cost links transfer decisions from one economic actor to another (domestic and foreign) in the material product chain. Any useful assessment of a certain measure should take these effects into account. Therefore the model not only describes the material flows for the *Netherlands* but also for *Western Europe* and the *World* as a whole.

Figure 2.2 Material Flows in an open economy



2.5 Delineation of the model

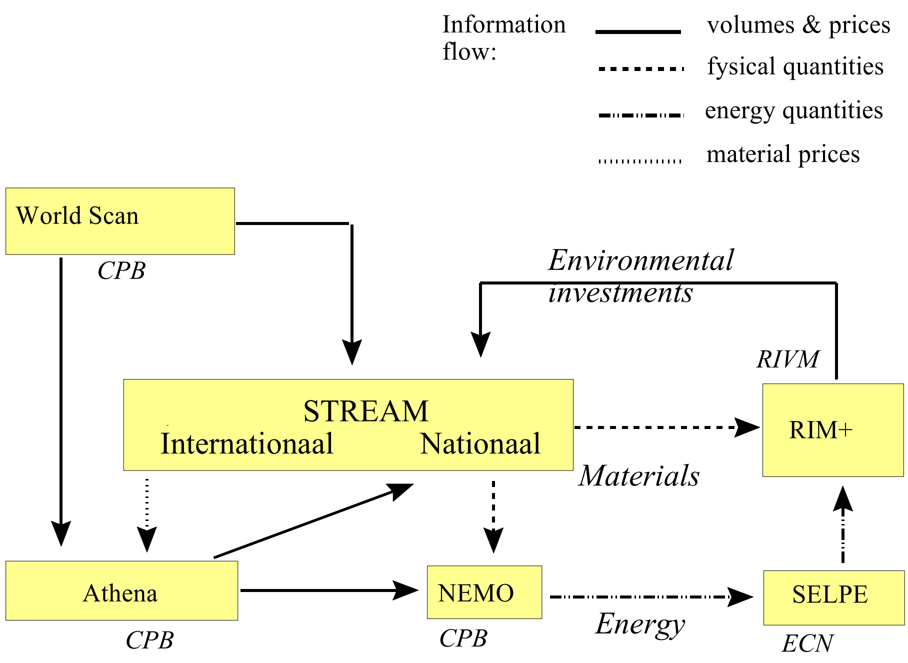
STREAM is aimed at analysing the relations between the environment and economic activity. In order to focus attention on the key factor in this relation, which are the material flows, the model is limited on both ends. Firstly, the income generating process and the labour and capital markets, are left outside the scope of the model. Secondly, the calculation of emissions from physical production and the investments in end-of-pipe solutions to reduce emissions are not considered here.

Although material use and energy use are largely complementary, the model also ignores the energy markets. The energy markets are too intricate to deal within this model.

Finally, the model is in the first instance limited[3] to seven bulk materials: These are: *steel, aluminium, plastic, paper, ammonia, phosphor and potassium*. Together, these materials account for most of the energy use and emissions in manufacturing.

Information about the ignored markets and mechanisms can be retrieved from other models of CPB and RIVM. Consequently, STREAM cannot be used independently from these models. The relations between the different models involved are presented in figure 2.3.

Figure 2.3 Partial equilibrium model and its links to other models.



World-Scan, the international economic model of CPB provides information about world and regional economic growth, structural change of the economy , wages, interest rates, exchange rates, inflation and so on. Athena, the national economic sector model

[3] Later, the model will be also applied to building materials (cement, glass and bricks) and energy carriers (oil products and electricity).

of CPB provides the same information for the national economy. This economic information in monetary terms is input for STREAM, which estimates the level and composition of national and international material flows consistent with the macro economic perspective of World-Scan and Athena[4].

The output of STREAM in physical terms is used in NEMO, which calculates the national demand for energy. Next, the SELPE model of ECN determines the composition of energy carriers to meet energy demand. From this, the energy related emissions can directly be derived by the RIM+ model of RIVM. The physical process information from STREAM is also used directly in RIM+ to derive the non-energy related emissions.

The separate analysis of macro or sectoral economic variables, specific physical processes in relation to economic activity and emission abatement activities, may raise serious consistency problems. These problems can be considerably mitigated by using the models in an iterative way and allowing feedback information to be transferred from one model to the other. For instance, the environmental protection investments calculated by the RIVM models can be used as an input in STREAM to make physical production consistent to the antipollution costs in the industries.

2.6 Conclusions

STREAM is a partial equilibrium model with three markets: raw materials, materials and scrap. The model describes the material flows of steel, aluminium, plastic, paper, ammonia, phosphor and potassium. Material producers can choose between primary and secondary production and technologies that distinguish six input factors: labour, capital, electricity, coal, oil, gas and raw material or scrap.

The model describes the material flows and prices for the Netherlands, Western Europe and the World. It can be used for the construction of material scenarios and for materials related environmental policy analyses. Moreover, STREAM links the macro economic models of CPB to the environmental models of RIVM.

[4] Because STREAM is a market oriented model within an international context the model also provides price information about raw materials, materials and scrap. This information is used to improve import price assumptions for the national economy.

3. Main topics in material analysis

3.1 Introduction

Economic actors make decisions about the supply of their output and the related demand for input. These ex-ante decisions are balanced on the markets for inputs and outputs by price adaptation. The markets are related to each other because each economic actor operates at least on two markets: the output market and the input market(s).

This chapter discusses the supply and demand relations that link the economic actors in the material-product-chain. (see figure 2.1 and 2.2). Theoretical arguments and empirical evidence amplify the chosen specifications, which determines the characteristics of the model, its ability to reproduce historical developments and its suitability to make meaningful projections. Figure 3.1 presents the main relationships in the model[5,6] , with the exception of the import and export relations. These relations are discussed within the context of five predominant themes in the field of material analysis:

- *De-materialisation, Inverted U-curves or Kuznets-curves*, are the topics of section 3.2.1. This section discusses the long-term relationship between economic growth and the product incorporated material demand of the *final users*. Figure 3.1 (relation 1) indicates that apart from GDP, material demand is affected by the own material prices and the energy prices.

- *Recycling* is the issue in section 3.2.2. This section enters into the factors that favour the use of secondary materials by the *product industry*. Figure 3.1 (relation 2) shows that the penetration of secondary materials depends much on the relative cost price of primary and secondary materials. These in turn depend on the prices of energy, raw materials and scrap.

[5] A more detailed description of the model is given in appendix A.

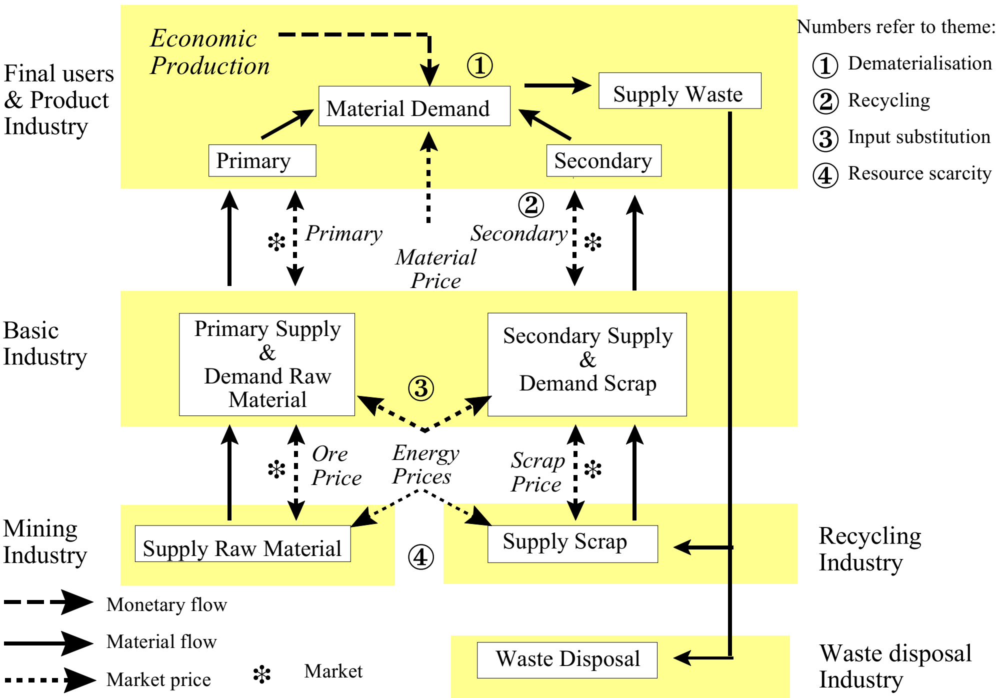
[6] The model applies a reduced form approach for product industries and final users together. The material flows between these two sectors and between the different sectors in the product industry will be further analysed in the MUSSIM project. The project, financed by the Netherlands' national research council (NWO), is a joint research project on environment and economy of Free University Amsterdam (VU), Institute for Environmental Studies (IVM), Wageningen University, National Institute of Public Health and the Environment (RIVM) and CPB.

● *Input-substitution* is the theme of section 3.2.3. This section deals with efficient use of inputs in the production process of the *basic industries* (relation 3). The efficiency is encouraged by the input prices. Especially, low energy prices may depress efficiency and thereby increase environmental pollution.

● *Resource scarcity* is addressed in section 3.2.4. This section deals with the long-run supply of raw materials by the *mining* and scrap by the *recycling industries* (relation 4). It shortly examens the increasing marginal cost problem in these sectors.

● *International trade* is the last issue in relation to material flows. Section 3.2.5. pursues the question of the international allocation of the productive capacity of the *basic industries*.

Figure 3.1 Model relations and themes in materials analysis



The markets in the model exhibit *excess capacity* in the short run. This is consistent with the historical data. They show persistent periods of idle capacity at bottom prices. The data also show that, if demand is on the edge of full capacity supply, the material prices rise sharply. This restrains material demand to the full capacity level and prevents rationing. In the long run however full capacity equilibrium prevails. Price and quantity signals, and market expectations direct the investments and therefore the production capacity to a market clearing equilibrium.

3.2 Demand and supply relations

The topics outlined in the previous section are related to specific developments on the demand or the supply side of the material markets. This section discusses each of the five topics and justifies the chosen specification of the demand and supply relations that are used in the model to describe the economic processes related to these main themes.

3.2.1 De-materialisation

Final users play a predominant role in the proportion and composition of the material flows in the economy. They spend their income on a variety of products according to their preferences, income level and relative prices. The product industry is another important player in the field because it chooses the material quantity and composition of each product on the basis of available technologies and input prices.

The model does not distinguish between final users and product industries. They are aggregated to one category: material users. Together they determine domestic material demand in the economy. Moreover, the model describes the material demand as an *Intensity of Use* relation at the macro economic level. Empirical investigations reveal that the material intensity to GDP (the ratio between material use and GDP) exhibits a bell-shaped relation in the long run. Figure 3.2 shows the intensity of use relation of the USA for several materials.

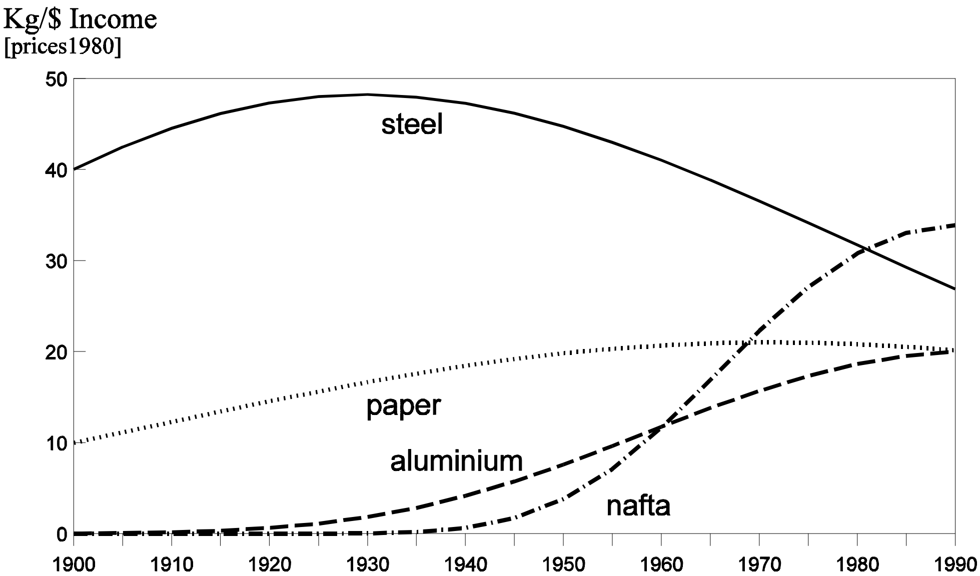
The bell-shaped intensity of use indicates different phases in the relationship between material and economic activity. The upward slope of this so called *inverted U-curve* is the phase of innovation, characterised by many new applications of the materials accompanied by strong cost price reductions. This development levels off when applications get exhausted and consumer saturation turns up. The downward slope is the maturity phase, characterised by substitution of other materials and by saturation accompanied by a continuous improvement of the material efficiency.

Figure 3.2 indicates that the USA is on or moves in 1990 to the downward slope for the depicted materials. Several empirical investigations [Simonis, 1989][Jänicke, 1989] reveal that the intensity of use has fallen substantially since the first oil crisis in 1973.

The transition from a manufacturing economy towards a service economy may have contributed to this development. Indeed, in the mid-seventies the leading role of the manufacturing industries in economic growth has been taken over by the services industries. However, it is difficult to relate this sectoral phenomenon to the inverse U-curves of specific materials, that appear to have their own dynamics and phase. It might be that these inverse U-curves depend more on technological trends than on sectoral trends.

The empirical evidence for the *de-linking* process between material use or emissions and

Figure 3.2 Material intensity of the USA



economic activity has been scrutinised [Ecological Economics, May 1998]. Critics [De Bruyn and Opschoor, 1994] maintain that the inverted U-curve is not stable and that instead a N-shaped relationship can be observed over the last two decades. Our data confirm this relationship in the last two decades, but also indicate that this is just an aberration from an inverted U-curve that spans about two centuries. The N-curve is caused by fluctuations of the energy price and investment activity in that particular period.

It has also been argued that the downward slope in the intensity of use is the result of reallocation of industrial activity from industrialised countries to less developed countries. Data do not confirm this tendency for the basic industries and it is very unlikely for the product industries in general. Indeed, the position of the OECD as net exporter of basic materials has been weakened but is not reversed. Moreover, the material import flows to the OECD are small relatively to demand. For instance, the steel import ratio of demand is .065. So, for relatively closed economic regions such as Western Europe, the USA and total OECD the observed material demand closely represents real final material use.

STREAM applies a simple macro relation to describe the material demand:

Material demand:

$$D = D_0 \times Y^{[\beta - \alpha t]} \times IY^{\gamma} \times [\frac{Pe}{Py}]^{\eta} \times [\frac{P}{Py}]^{\varphi}$$

This equation derives material demand (D) from macro economic production[7] (Y), the ratio of real investment to GDP (IY), the real energy price (Pe/Py) and the real or relative material price (P/Py).

The decreasing income elasticity (β-αt) defines the above mentioned (autonomous) innovation and saturation processes in which the inverted U-curve of the intensity of use originates. When the elasticity is greater than one, the intensity of use to GDP rises and vice versa. The IY term describes the effect of relative investment activity and Pe/Py the energy price effect on demand. These two variables contribute to the observed N-curve in the last two decades. The own real price P/Py balances material supply and demand. Several empirical investigations [Tilton, 1990] [Auty, 1985][Choe, 1988] reveal that the effect of the own price is not so easy to indicate. Table 3.1 presents the calibrated values of the elasticities used in the model. Most of the income elasticities show a substantial fall over the period 1960-1995. This confirms the inverted-U hypothesis. The average decline[8] of the income elasticities was about 1% per year. Nevertheless, in 1995 income elasticities of most materials are still above one. Therefore, material demand is still strongly coupled with economic growth. This is especially true for plastics.

The real investment ratio has a significant impact on steel and paper use. Apart from plastic demand, all own price elasticities are small or modest. The energy price affects

[7] For the Netherlands a material weighted sectoral production index is used. GDP is used for international demand relations.

[8] This trend is used in the model to extrapolate the income elasticities.

the material demand in two ways: by a direct *forward cost linkage* via the material price (P) and by an indirect *backward demand linkage* via the final product composition and the material content of the final product. An illustrative example of the latter is the effect of the gasoline price on the material content and composition of cars. So, the real energy price (Pe/Py) in the demand equation refers here to energy price payed by consumers and other final users. These indirect demand effects of the energy price have been found for steel, aluminium and paper demand. There may be a similar effect for plastics, but the plastic price and the energy price are so much related that it is impossible to discriminate between the direct and the indirect effect of an energy price increase.

Table 3.1 Elasticities of the material demand equations in OECD countries

material	Income elasticity 1960 [a]	Income elasticity 1995 [a]	Investment ratio elasticity	Own price elasticity	Energy price elasticity
steel	0.9	0.65	0.75	– 0.2	– 0.1
aluminium	2	1.5	0	– 0.2	– 0.05
plastic [b]	3.8	2.7	0	– 0.9	–
solvents	2.3	1.3	0	– 0.5	–
paper	1.1	1	0.4	– 0.4	– 0.025
nitrogen	1.8	1.2	–	– 0.5	–
phosphate	1.1	0.6	–	– 0.5	–
potassium	0.8	0.4	–	– 0.5	–

[a] (β-αt)

[b] The petrochemical production is divided into the production of building blocks (e.g. ethylene) and the production of plastics(polymers) and solvents.

Although the inverted U-curve is stable and easy to specify, a serious shortcoming of this approach is that it provides little insight into processes behind the curve. Hence, it is only of limited help in designing environmental policy aimed at the process itself. Nevertheless, this research project takes the inverted U approach as a starting point for modelling material demand.

Although sectoral material demand is generally not observed for the Netherlands, the specification above is applied to the Netherlands on sectoral level. Instead of GDP, the material weighted sectoral gross economic production is used as the volume indicator.

One should expect, that the explicit enclosure of sectoral information into the specification alters the above coefficients. Indeed, the decline of the aggregate income elasticity implicitly includes the effect of the changing sectoral structure. So, adding this information explicitly must reduce the elasticity decline and thus α. However, with the exception of aluminium this shift cannot be observed. This suggests that the de-materialisation process is predominantly an intra sectoral process.

3.2.2 Recycling

Material recycling may reduce emissions substantially. It reduces physical production of the mining industry in the beginning of the material product chain and also the waste flow to deposits on the other end. Moreover, secondary material production from waste is generally much cleaner than primary production and needs less energy. For instance, the energy demand of the secondary production process of aluminium is only 5% of the primary process. However, waste collection and recovery activities of the recycling industry also require energy and generate emissions. This in turn may diminish the overall environmental gain of recycling.

Product industries can choose between primary and secondary materials as input for their production processes. The choice depends on the material quality required and on relative prices. Generally, secondary materials exhibit less quality, so primary and secondary materials are usually not pure substitutes for each other. Nevertheless, for specific applications primary and secondary materials are such close substitutes that price differences cannot be maintained. This is called the *law of one price.* In that case, the relative cost at basic industry level reflects a great deal of the comparative advantage of one process over the other. The model describes the substitution between primary (Dp) and secondary (Ds) materials as an inverse hyperbolic function ($\beta \leq 0$) of the relative cost price (Pqp/Pqs) of the basic industry:

Primary/Secondary

$$\frac{Dp}{Ds} = f(..) \times Sps \times [\frac{Pqp}{Pqs}]^{\beta} \times IY^{\gamma}$$

with: f(..) – other specific factors.
Sps – long-run trend.

If the cost price of the primary process (Pqp) increases relatively to the cost price of the secondary process (Pqs) the demand of primary materials (Dp) will decrease in favour of the secondary materials. Both production processes primarily differ from each other in material input: minerals or scrap, and in energy use. Consequently, substitution between primary and secondary materials originates largely in changing scrap and energy prices. Apart from price effects, the composition of final demand can affect the share of secondary materials. Indeed, high investment rates primarily support secondary aluminium demand, mainly due to the use of this material in construction industries.

Table 3.2 Elasticities of substitution between primary and secondary production

material	Price elasticity	Investment ratio elasticity
steel	3	0
aluminium	2	2
plastic	2	–
paper	4	0

Table 3.2. presents the elasticities of substitution. The values of the price elasticities are strikingly small for these apparent close substitutes. This confirms the notion that primary and secondary materials are imperfect substitutes because of quality differences.

In a dynamic simulation, the above specification implies that relative cost price *changes* will lead to substitution between primary and secondary demand. However, relative cost price changes can only partially explain the continually growing share of secondary materials. The observed trends may be due to the lower price *levels* of secondary materials or to scrap augmenting technological progress. The first root suggests the existence of long-term price induced adaptation processes. In that case, the above specification has to be adjusted. This can be done by the addition of a multiplicative term S representing the long-run penetration of secondary materials:

Long run ratio:

$$Sps = Sps(-1) \times [\frac{Pqp}{Pqs}]^{\sigma} + Sps^{0}$$

This long run material share allows for a complete takeover by secondary materials because of price level differences but also because of autonomous processes, such as process and product innovation in the product industry. Model simulations support a very high value between .1 and .075 for σ. This implies that a 10% price difference gives rise to a 1% per year market loss. Furthermore, the positive value of Sps^0 of about .01 indicates that other exogenous processes, such as technological progress favour the use of scrap with 1% per year. Despite these secondary materials enhancing developments, a 100 percent recovery rate is only possible at extremely high costs. Therefore, in the long-run scrap prices will rise, the cost price difference will squeeze and ultimately a long-run equilibrium with less than 100% recovery will prevail.

3.2.3 Input substitution and technical progress

If the substitution possibilities for natural resources are considerable and technical progress is brisk, sustainable economic growth can be achieved. Indeed, the *factor four* discussion [Weizsäcker,1997] suggests that sustainable growth can be compensated for economically by technical progress. Other studies [Blok, 1994] also suggest that the energy efficiency can be improved substantially at little (net) investment costs. These recent studies are based on bottom-up information. Two decades ago, when information technology was less able to handle large technical data sets, research in this field was focussed on the estimation of substitution elasticities and technological trends [M. E. Slade, 1981] within neoclassical models. Here, this elasticity approach is used for simplicity and its analytical advantages: it accounts for the substitution among all inputs, not just between energy and capital, and the results can be added up to calculate the cost price of the produced materials and its impact on material demand. Moreover, bottom up information can easily be taken into account by assigning specific values to some elasticities [Koopmans, CPB 1999] and the compact representation allows for a dynamic vintage approach without exceeding the limits of convenience.

Following conventional practice of neoclassical substitution analysis, the model applies a Translog cost function [Varian, 1985]with six inputs: *labour, capital, coal, oil, natural gas and electricity*. This quadratic function of the input prices is very flexible[9]. It is able to represent fixed as well as switching technologies and all the smooth variants in between. Furthermore, it is based on three assumptions: predetermined input prices for entrepreneurs, constant returns to scale and cost minimising entrepreneurs.

The last assumption yields an explicit set of factor demand equations:

Factor demand i :

$$X_i = [a_i + \sum_j b_{i,j} \times \ln(Px_j)] \times \frac{Pq}{Px_i} \times Q + c_i \times Q$$

with: a, b, c-coefficients

[9] The Translog cost function is also an approximation of the CES cost function [Kmenta, 1967]

such that: $\sum_i a_i = 1 \qquad b_{i,j} = b_{j,i} \qquad \sum_j b_{i,j} = 0$

Factor demand can be calculated directly from input prices (Px) and the production level (Q), since the cost price (Pq) is a quadratic function of the input prices:

Cost price: $$\ln(Pq) = a_0 \times t + \sum_j a_{i,j} \times \ln(Px_j) + \frac{1}{2} \times \sum_i \sum_j b_{i,j} \times \ln(Px_i) \times \ln(Px_j)$$

with: t – trend

a_0 – coefficient (negative)

Table 3.3 Own price elasticities of (substitutable) factor demand and cost reducing technological progress in primary and secondary material production

material	Labour	Capital	Coal	Electricity	Oil	Natural Gas	Technological progress
primary	% per year)						
steel	– 0.75	– 0.5	– 0.7	– 0.7	– 0.7	– 0.7	1.75
aluminium	– 0.8	– 0.85	– 1	– 0.8	– 1	– 1	1
building blocks	– 0.75	– 0.9	–	–	– 0.7	–	1
plastic	– 0.5	– 0.6	–	–	– 0.6	–	3
paper	– 1.5	– 0.7	– 0.5	– 1	– 1	– 0.6	2
nitrogen	– 1.1	– 0.5	–	– 1	–	– 0.9	1.5
phosphate	– 1	– 0.5	–	– 1	–	– 0.9	1.25
potassium	– 1	– 0.5	–	– 1	–	– 0.9	1.5
secondary							
steel	– 0.9	– 0.55	–	– 0.6	– 0.7	– 0.7	1.75
aluminium	– 0.8	– 0.65	–	– 1	– 0.95	– 1	1
paper	– 1.5	– 0.7	– 0.5	– 1	– 1	– 0.6	2

The own price elasticity depends on the values of coefficients a_i and b_{ij}.

The first part of the demand equation is the Translog demand function. It suggests that an input factor can be replaced completely when its price increases infinitely. However, energy substitution in any material production process is limited to the *thermodynamic minimum* [Weijnen M.P.C., 1997]. This theoretical minimal energy use covers for most materials a substantial part of the overall energy use. For instance: 45% of the energy use in the ammonia production and 60% of the energy use in the methanol production is not substitutable. Therefore, a second term is introduced to represent this technical minimum demand per unit output. Furthermore, factor demand is proportional to material production: if production doubles factor demand will double too.

Technical progress (t) is exogenous in the model and leaves the relative factor intensity unchanged (Hicks neutral). Factor augmenting technical change can be introduced easily but there was no empirical urge to do so. The impact of technical progress on natural resource use is twofold: it reduces the resource demand per unit of material, but on the other hand it also reduces the cost price of materials and hence encourages material demand. This forward cost price effect of improved resource efficiency on demand is also known as the *rebound effect*.

Table 3.3 presents the own price elasticities of factor demand. The table indicates strong substitution possibilities for all the input factors. The energy elasticities appear to be much higher than in NEMO [Koopmans, CPB1999, table 3.1]. However, the elasticities in table 3.3 refer to substitutable energy use only. In contrast to NEMO the above mentioned thermodynamic minimal energy use is not included in the elasticities of STREAM. Therefore, a direct comparison is not allowed. A cursory glance at the energy price variants of both models shows that the price sensitivity of total energy demand of the basic industries in NEMO is about a factor one to a half as large as in STREAM.
This remaining difference in sensitivity may have various sources. First, the substitution elasticities of STREAM are determined by calibration and simulation of historical developments. However, the elasticities may be changed in time and a satisfying simulation does not always guarantee that the specifications and parameter values of the model are correct. Second, the substitution elasticities in NEMO are based on bottom up information from current literature gathered in ICARUS [Beer, J.G. de, 1994]. However, bottom up information is typically biassed to little substitution possibilities due to overlooked current technologies and to yet unknown future technologies. On the other hand, this bias may be mitigated because the actual savings are generally lower than the theoretical savings recorded in literature. Third, the STREAM elasticities of the basic industries also include energy conversion techniques such as CHP (Combined Heat and Power technics) while NEMO considers these techniques separately.

3.2.4 Resource scarcity

The economical process extracts an increasing amount of raw materials from geochemical reservoirs.

The reserves that are easy to exploit get exhausted and the demand for materials can only be met by exploitation of the marginal fields at high costs. This long run development of *decreasing returns to scale* in the extraction activities is formalised by an exponential function of the cumulative mineral production (Qg_{cum}):

Marginal extraction costs: $$\frac{Pg}{Py} = \alpha_0 \times \lambda^t \times \exp(\beta \times Qg_{cum})$$

or in logarithmic differences:

Price (real) change : $$\mathrm{dln}(\frac{Pg}{Py}) = \ln(\lambda) + \beta \times Qg$$

The exponential relation has been derived [Kroch, 1979] from the generally observed geological distribution of scale and grade of mineral reservoirs in the earth crust. The exhaustion effect of mineral extraction (Qg) did not lead to increasing real prices up to now, due to fast cost reducing technical progress (ln(λ)). In the long run, technical progress has to keep pace with the exhaustion effect of the mineral extraction level to maintain real prices at the same level.

The existing reserves of raw materials analysed in the model are abundant. The price development is therefore predominated by cost reducing technological progress of about 1.5% per year.

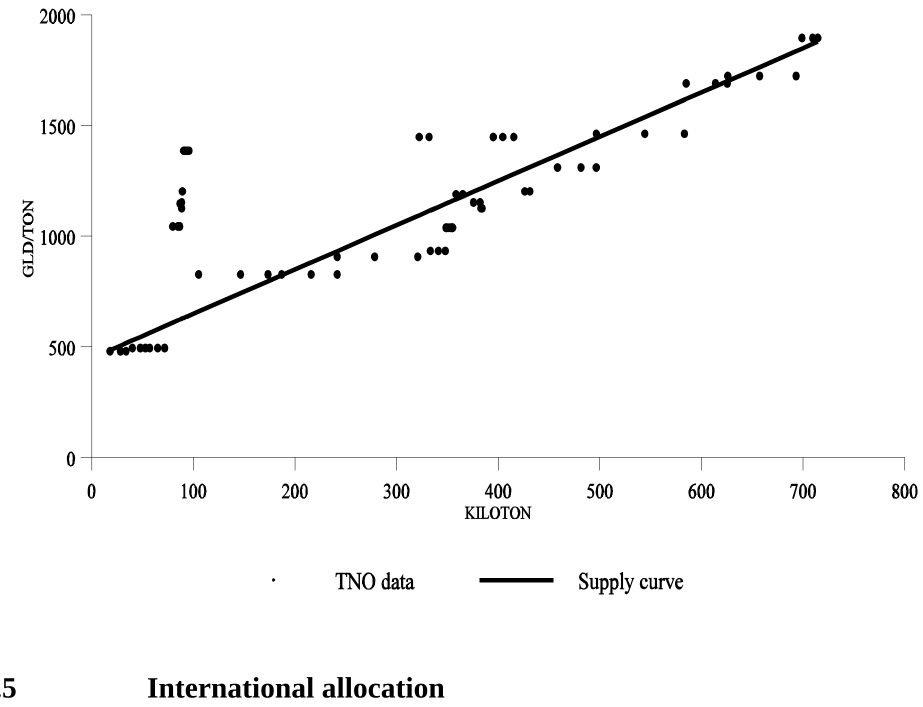
Decreasing returns to scale also arise in the recycling industry. An increasing recovery rate of secondary materials (Qs) from waste (W) can only be achieved at rising real costs (Ps/Py):

Real scrap price: $$\frac{Ps}{Py} = \lambda^t \times [\alpha_0 - \gamma \times \ln(1 - \frac{Qs}{W})]$$

The functional form has been derived from TNO data about the recycling costs of aluminium [TNO-MEP,1997]and plastic waste [TNO-Industrie,1997]. Figure 3.3 shows these recycling costs for all different types of plastic (see dots) used in the Netherlands economy. These plastics are put in order [RIVM, van Dam and Blom, 1997] according to increasing profitability: revenue minus costs. The data show a rough picture of the marginal costs of plastic recycling. The linear curvature of the observed relation is striking. One should expect that the extraction of the last ton of plastic from the waste flow is extremely expensive. Other empirical investigations [Starreveld, 1994] reveal a more than proportional increase of the marginal recycling costs. Therefore, the model employs a specification that is linear for the cheap options and allows for escalating marginal costs if the recovery rate (Qs/W) is close to one. In other words: the recycling activity exhibits decreasing returns to scale.

The TNO data support a slope parameter value: γ=1 for plastic and γ=6 for aluminium. The model uses γ=1 for all kinds of scrap because it was impossible to reproduce the historical development of the aluminium scrap price (Ps) and the recovery rate (Q/W) simultaneously from the observed steep slope parameter value based on the TNO data.

Figure 3.3 The marginal cost curve of plastic recovery

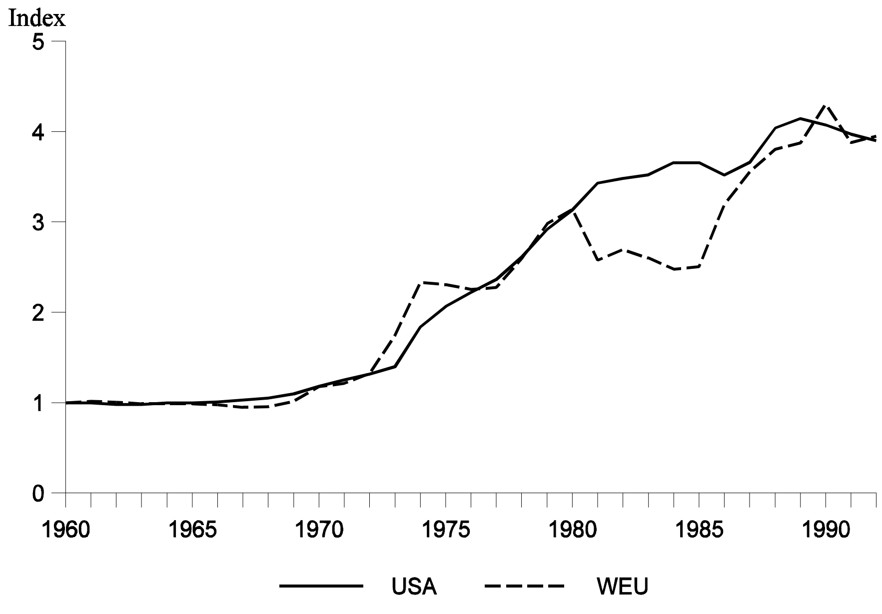


3.2.5 International allocation

Comparative advantages determine international allocation of production capacity. The location of geological reservoirs of minerals and energy sets the location of the mining industry. Basic industries are generally located near coasts and along rivers to reduce transport and production costs. Indeed, the West-European oil and petrochemical industry makes its presence felt in the Netherlands because of the favourable location between the oil production fields and the concentration of final users in the Rhine basin. This advantageous economic position has drawbacks for the national energy consumption and emissions.

Geographical advantages are not the only factors that determine the location of industrial activities. Other factors such as qualified labour, institutions and government policy also affect international allocation. The strong competition in international material markets makes the allocation highly sensitive to the costs and availability of all factors of production and to policy changes. The material flows in an open economy may shift radically because of reallocation of production capacity over countries. Such a shift may create a so called *environmental leakage*.

Figure 3.4 Steel producer price in the USA and EC in dollars



The market price for materials is the same for domestic and foreign producers due to the *law of one price*. Figure 3.5 confirms the notion that material prices cannot diverge for long across different parts of the world. For steel however, the figure also shows that economic instability and especially exchange rate fluctuations may induce regional price differences. In general comparative advantages of countries and regions are not so much reflected in market prices but in cost price differences.

In the model, relative cost prices and capacity shares determine the quantity of the physical import and export flows of raw materials, scrap and materials:

Export: $$X = fx(..) \times S \times [\frac{Pq}{Pq*}]^{\beta} \times D*$$

Import: $$\frac{M}{D-M} = \frac{fm(..)}{S} \times [\frac{Pq}{Pq}*]^{\eta} \times D$$

with:	fx(..) and fm(..)	– other specific factors.
	S	– long-run market share

The export flows (X) depend on the international material demand (D*) and the market share of domestic producers on the international market. The market share depends on specific technological, geological and geographical factors and on the relative cost price (Pq/Pq*) of domestic versus foreign producers. The import (M) flows are specified in the same way.

Table 3.4 presents the price elasticities of the import and export relations of materials and scrap. The West-European price elasticity of most material exports is about – 4. The paper industry is (was) a relatively sheltered sector within Europe and therefore shows a relatively low price elasticity. The low value of the price elasticity of aluminium export is not so easy to explain. The West-European home markets for steel, aluminium and plastic are less vulnerable to price changes. Their import price elasticities are half as high as for export. This may be the result of price discrimination and protection, qualitative differences between export and import, and of external effects such as a more developed after-sales service network of the home producer.

The West-European price elasticities for scrap trade are about the same as for materials. The Netherlands material price elasticities for import and export demand are roughly twice as high as for Western Europe. Contrary to Western Europe, the Netherlands price elasticities of scrap trade appear to be somewhat lower than those of material trade.

Table 3.4 *Price elasticities of import and export of Western Europe and the Netherlands*

	Western Europe		Netherlands			
	export	import	export		import	
material \ process			primary	secondary	primary	secondary
steel	– 4	2	– 7.5	– 4	4	2
aluminium	– 3	2	– 8	– 8	6	6
building blocks	– 5	4	– 10	–	8	–
plastic	– 5	2	– 8	–	4	–
paper	– 2	2	– 8	– 8	5	5
nitrogen	– 4	4	– 10	–	8	–
phosphate	– 4	4	– 8	–	10	–
potassium	– 4	4	–	–	–	–
scrap						
steel	– 5	2	– 6		2	
aluminium	– 4	2	– 6		4	
plastic	–	–	–		–	
paper	– 1.5	1	– 4		4	

The price term represents the Armington trade specification. In a dynamic simulation, this specification implies that only relative cost price changes will lead to a change of the market share on the international and the domestic market. However, the ongoing penetration of Newly Industrialised Countries on the material markets has not been accompanied by continuous relative price reductions. To address this issue, cost price differences (in levels) should be taken into account [Gielen, 1998] as in traditional Hekscher-Ohlin trade specifications.

Cost price differences between countries, subject to one international market price, imply differences in profit rates and consequently in investment rates. Accordingly capacity shares shrink or expand continuously as long as cost differences last.

In order to improve the long-run consistency of the model, the trade specification also includes a cost price difference effect:

Long run market ratio: $$S = S(-1) \times [\frac{Pq}{Pq*}]^{\sigma} + S^{0}$$

This long run international market ratio allows for a complete market takeover by a certain region. Model simulations support high σ values (.1) for fertilizers, medium values (.05) for metals and low values (.01) for petrochemical and paper.

The above export and import specifications are also used for the scrap trade relations. However, international cost price differences may persist in these markets without affecting the market share. Observed scrap price differences between the USA and Western Europe and even within Europe suggest that local markets prevail the scrap market. These local markets persist due to high transport cost relative to the scrap value per kg.

3.3 Calibration of the model

Relative prices play a key role in the model. Due to the law of one price the relevant price differences between suppliers cannot be observed. Instead, the cost price differences are used as an indication of the market power of entrepreneurs to undercut prices. However, official statistics generally do not provide information about cost prices. Hence, cost prices must be derived from input demand and price information. The problem of unobserved variables complicates the estimation of the relations in the model. Moreover, the interactions between the relations call for a simultaneous estimation procedure. For simplicity, the parameter values of model have been determined by *calibration*, viz. by gradual comparison of model outcomes and observations to indicate the value of the parameters in the model.

A great deal of the research effort has been put into the search for data and the construction of consistent time series. The credibility of the model for policy makers, captains of industry and environmentalists as a useful tool for analysing environmental policy depends much on the ability of the model to represent real world situations and processes. Consequently, data-collection is a crucial part of this project. The greater part of this data set will be published later on.

STREAM contains more than 500 demand and supply or price relations. The parameters of these relations are primarily based on time series over the period 1960 to 1995 gathered by various national and international statistical offices, such as: United Nations, OECD, Eurostat, US bureau of the Census, Statistisches Bundesamt, and

Statistics Netherlands (CBS). Moreover, technical data and process information from ECN, TNO, Novem and RIVM are incorporated.

Many gathered time series are incomplete or inconsistent. Observations from different sources, using different definitions, and observations of closely related processes from comparable countries were used to reconstruct a general picture about the main developments on the material markets. The fragmentary character of the available observations sometimes forced us to use methods that are more conventional in archeologic research: the reconstruction of an artefact from a few excavated relicts.

Consequently, some parameter values in the model are quite uncertain because of the limited availability of time consistent data and therefore the outcomes of the model must be used prudently.

The limited availability of time consistent data also restricts the scope of the model. The only material demand indicator of countries and regions available, is the so-called *apparent consumption*, that is the material production minus export plus import. The apparent consumption is related to the direct material use of the product industry. In an open economy however, the apparent consumption may substantially deviate from the real consumption, because of the unobserved indirect (via intermediary products) material consumption by the product industry and final users. Indeed, the materials incorporated into the import and export of finished products may present a complete other picture of the actual material demand. However, the lack of information about the development of these intermediate material flows does not allow to distinguish in the model between the product industry and the final users.

4. The model at work

This chapter presents a variety of model outcomes to give an impression of the possibilities and limitations of the model. The model enables us to forecast future developments on the material markets. Moreover, it also gives an indication of the effectiveness and implications of environmental policy instruments at the Western European level and for the Netherlands only.
The outcomes of the model depend largely on information about economic and technical developments in the past. Therefore, this chapter also discusses historical developments and their relevance as a point of reference for the future.

This chapter consists of three parts: Section 4.1 outlines an economic baseline scenario for Western Europe and the Netherlands that provides a consistent set of plausible values of the exogenous model variables. Section 4.2 presents the model results in the baseline scenario and discusses the base-line projections of the national and international primary and secondary material flows, the development of the production processes and their input composition, and the raw material, material and scrap prices. These projections provide a coherent picture of future demand for and supply of natural resources. Section 4.3 elaborates on the sensitivity of the model outcomes to variations in economic growth, prices and policy measures. It depicts the separate mechanisms in the model more clearly and illustrates the effects of shifts in economic conditions or material policy.

4.1 Base-line scenario 2000-2020

A macro economic base-line scenario of the world economy featuring economic and social trends that are more or less in line with historical trends (1960-1995) serves as a point of departure in the elaboration of the materials scenario of Western Europe and the Netherlands. This macro economic scenario provides a consistent set macro economic variables, which are exogenous in the model due to its partial character. Table 4.1 shows the key exogenous variables of the model.

The macro economic base-line scenario is not a well thought-out vision of possible future economic development but only a set of consistent and plausible assumptions. The first assumption in this scenario is that economic growth in the OECD countries is somewhat lower than in the past due to the modest increase of the labour participation and due to the sectoral shift from manufacturing to the services industries. Indeed, labour productivity growth in services industries is substantial lower than in manufacturing. This sectoral shift affects the aggregate labour productivity negatively. So, economic growth of the OECD countries is fixed at a rate of 2.5 percent per year, split up into .25% employment growth[10] and 2.25% labour productivity increase. The LDC's are assumed to grow with 4.5 percent per year, split up into 1.75% employment growth and 2.75% labour productivity increase.

The second assumption is, that the real investments ratio to GDP and the income share of labour in total GDP remains unchanged. Consequently, real investments develop at the same growth rate as GDP and the real wage rate keeps up with labour productivity.

The third assumption is that, the real interest rate is equal to the long-run level of 4 percent. And finally, it is assumed that the real energy prices remain unchanged at a level, which is consistent with a crude oil price of $20 per barrel.

Table 4.1 *Economic base-line scenario (2000-2020)*
[Historical values (1970-1995) between brackets]

	Production	Cereals[a] production	Investment	Real wage rate	Real Energy price	Interest rate
			(yearly % change)			(percentage)
Developed Countries	2.5 [2.8]	1.0 [1.2]	2.5 [2.5]	2.0 [3.0]	0 [2.2]	4 [3.0]
Less Developed Countries	4.5 [4.7]	2.5 [2.8]	4.5 [6.0]	2.75 [n. a.]	0 [2.2]	4 [n. a.]

a] Cereal production is the relevant volume indicator for fertilizers demand.

Sectoral growth figures of the Netherlands are used for the calculation of national material demand. They are based on the average ratio of sectoral and GDP growth[11] in the CPB scenarios 1995-2020 published in: 'The economy and its physical surroundings' [CPB,1997].

[10] The employment growth figures are based on the labour supply trends in " Scanning the Future" [CPB, 1992]

[11] If y_i is the growth rate in sector i and y the growth rate of GDP in the CPB scenarios, than the growth rate of sector i in the technical scenario is: $Y_i = y_i / y*Y$, with Y is the GDP growth rate in the technical scenario. The ratios y_i/y have more or less the same value in the different CPB scenarios.

Table 4.2 presents the gross production growth figures of the main material using sectors. The differences in growth compared to the historical period mainly arise from the low investment growth of 1.2% per year in the period 1970-1995. Especially the construction and building materials industry experienced a serious setback in that period.

Table 4.2 also indicates that the domestic demand for products of the basic industries is highly concentrated in some product industries. Therefor the development of the gross production of these sectors is probably more indicative for material demand than for instance gross national product.

Table 4.2 The volume growth of gross sectoral production in the base-line scenario of the Netherlands and the shares of the product industries in domestic demand

Sector (SBI-1974)	2000-2020	1970-1995	Steal	Alum	Plastic	Paper
	(yearly % change)		(percentage share)			
Food products (20+21)	2.25	2.5	2.5	2.5	-	10
Paper products (26+27)	1.75	-	-	-	-	60
Chemical products (29+30+31)	4.75	4.25	2.5	5	80	5
Building materials (25+32)	1.75	0.5	5	25	5	-
Metal products (34+35)	2.25	2	47.5	50		-
Electro technical products (36)	3.75	3	15	7.5	10	-
Transport equipment (37)	1.25	0.25	10	7.5		-
Construction (5)	1.75	– 0.5	15	-	5	-
Trade and transport (6+7)	3.25	3.25	2.5	2.5	-	10
Services Industry (8+9)	3.25	3	-	-	-	10

Source: CPB scenarios. CBS: Material flows and input-output analysis [P.Konijn e.a., 1995]

4.2 Materials scenario

This section presents a World, West-European and Netherlands outlook for raw materials, materials and scrap based on the macro economic base-line scenario in section 4.1. It compares the base-line scenario results of the model with the historical developments of subsequently material demand, market prices, primary and secondary production, and the energy productivity in the basic industries.

Apart from the macro economic assumptions in base-line scenario, the following specific assumptions are made with respect to factors that determines demand, international trade and production of materials:

- The economic growth in all OECD countries is the same.
- All OECD countries face the same price development and the exchange rates remain unchanged.
- Institutional behaviour and materials related policy does not change in all OECD countries. There are a few exceptions. For instance, the Dutch fertiliser demand is further restricted to comply with the European regulations.
- The autonomous de-materialisation process continues at a rate of 1% per year for all materials (see also table3.1).
- The autonomous technological progress in the basic industries continues at the historical pace (see table 3.3).

All together, the first three assumptions above imply that the competitive position the Netherlands relative to Western European and OECD countries remain unchanged.

All above assumptions are rather rigorous. These assumptions may be relaxed but in that case a full-fledged economic scenario is needed to explain the differences in economic growth, market and institutional behaviour and government policy. These differences are abandoned here. However, deviation from this uniform development is allowed and analysed in the variants of the next section.

Material Demand

Table 4.3 shows that world material demand expands between 1% and 3% per year. This is well below the economic growth of 3.25% per year. The world aluminium, nitrogen and phosphates demand remain .5% to 1% per year behind the historical trends, mainly due to structural change and environmental policies in agriculture. On the other hand, world steel demand exceeds the historical growth rate because the relatively low energy price supports the steel intensive transport and energy equipment industry.

The OECD countries add greatly to the relative decoupling between material demand and economic growth. OECD material demand expands between .5% and 2% per year. The brisk development of plastic demand is compensated by a sluggish development of solvents. So, total demand for petrochemical products remains somewhat behind economic growth. It is assumed in the scenario that the restrictions on the use of fertilizers will not be tightened any further in most of the OECD countries.

West-European and Netherlands material demand are in line with the OECD countries. However, the extent of over-fertilization in the Netherlands will lead to additional regulations. These will restrict fertilizer use in agriculture and therefore reduce fertilizer demand further.

Table 4.3 *Material Demand by region/country. Scenario: 2000-2020, and historical development: 1970-1995*

	World		OECD		Western Europe		Netherlands	
materials	Scenario	*Hist.*	Scenario	*Hist.*	Scenario	*Hist.*	Scenario	*Hist.*
	% change per year							
steel	1.6	*1.5*	0.8	*0.2*	0.8	*– 0.1*	0.9	*– 0.1*
aluminium	3	*3.6*	1.5	*2.9*	1.5	*3.1*	1.5	*6.1*
petrochemical blocks	–	–	2	*2.6*	2.1	*2.4*	2.3	–
– plastic	–	–	2.9	–	3.1	*5.8*	2.9	–
– solvents	–	–	0.7	–	0.9	*– 0.1*	0.9	–
paper	–	–	1.9	*2.7*	1.9	*2.7*	2	*2.8*
nitrogen	2.5	*3.9*	0.8	*1.1*	0.6	*1.2*	– 0.6	*– 0.4*
phosphate	1.3	*1.9*	0.6	*– 0.8*	0.5	*– 2*	– 1.2	*– 2*
potassium	1.2	*1.1*	0.6	*– 0.4*	0.3	*– 1.2*	– 1.3	*– 2*

Material prices

Material and raw material prices are set on world markets. Table 4.4 shows that the real material prices decline in a range of .5% à 1.5% per year due to large productivity gains in the basic industries. These productivity gains also occurred in the past. However, the effect of the increased energy prices gave an upward bias to material prices in the period 1970-1995.

The real raw material prices of the large scale mining industries show a similar downward tendency. All raw materials in the model (energy is exogenous) are abundantly present in the earth crust. Hence, the effects of resource exhaustion are relatively small.

Table 4.4 Real material and scrap prices. Scenario:2000-2020, and historical development: 1970-1995

	World material price		World raw material price		West European scrap price		Netherlands scrap price	
materials	Scenario	*Hist.*	Scenario	*Hist.*	Scenario	*Hist.*	Scenario	*Hist.*
	% change per year							
steel	– 1.5	*0.3*	– 1.4	*–1*	– 1.7	*–3.5*	– 2.2	*–3.1*
aluminium	– 0.9	*–1.3*	– 0.8	*–1.6*	– 0.8	*–2.3*	– 0.7	*–2.5*
petrochemical Blocks	– 0.3	*2.1*	0	*2.1*				
– plastic	– 0.6	*–0.8*	–	–	– 1.6	–	– 1.1	–
paper	– 1.5	*0.4*	– 0.6	*0*	– 1.3	*–2.6*	– 1.1	*–2*
nitrogen	– 1	*–0.5*	0	*0.8*				
phosphate	– 1.4	*–0.9*	– 1.5	*0.7*				
potassium	– 1.5	*0.4*	– 1.6	*0*				

Scrap prices are primarily set on local markets. Diverging prices between markets induce trade flows which mitigate relative shortages or surpluses. Improving waste management and cost reducing technological progress of the recovery industry support the scrap supply relatively more than demand. Therefore, real scrap prices in Western Europe and the Netherlands decrease between 1.0% and 2.0% per year. This decline is modest compared to the historical downward trend because the marginal recovery costs increase if the recovery rate improves.

Material production

Material production in an open economy depends on foreign and domestic demand, and on the competitive power of the basic industries. The competitive position of the West-European basic industries has generally decreased between 1970 and 1995 in favour of energy rich regions. Especially the fertilizer industry suffered a substantial loss of the market share to the Middle East and Russia. Only the West-European steel industry improved its market position in the seventies and maintained its advantageous position ever since, despite several crises on the international steel market and thanks to government assistance.

Table 4.5 *Materials production, primary and secondary. Scenario:2000-2020, and Historical development: 1970-1995*

	total		primary		secondary	
materials	scenario	*hist*	scenario	*hist*	scenario	*hist*
	% change per year					
Western Europe						
steel	0.8	*0.5*	0.1	*−1.1*	1.7	*3.2*
aluminium	1.5	*2.9*	0.5	*2.1*	2.4	*4.3*
petrochemical Blocks	2.1	*2.4*	2	*2.4*	6.2	–
- plastic	2.7	-				
paper	1.9	*2.9*	0.8	*1.8*	2.9	*5.1*
nitrogen	0.6	*0.3*				
phosphate	− 1	*−3.5*				
potassium	− 0.5	*−1*				
Netherlands						
steel	0.5	*0.8*	0.5	*0.9*	− 0.2	*−2.4*
aluminium	1.2	*6.2*	0.8	*5*	1.7	*8.8*
petrochemical Blocks	2	*3*	1.9	*3*	5.8	-
- plastic	2.4	–				
paper	1.9	*2.1*	0.7	*−2.5*	2.2	*5.6*
nitrogen	1.2	*2.7*				
phosphate	− 1.5	*0.3*				

The scenario assumes that all West European basic industries can maintain their competitive position, with the exception of the phosphate and potassium industries. Consequently, production growth in table 4.5 is in line with demand development in table 4.3. Only the phosphate and potassium production remain behind demand accordingly to historic trends. Ample gas supply keeps nitrogen producers in the region.

The secondary producers expand their market share further at the costs of the primary producers. They gain advantage from decreasing scrap prices and relatively strong improving productivity. However, the penetration of secondary materials slows down compared to historical trends, mainly because the incentive of the energy price is absent. Moreover, if the penetration of secondary materials continues, the material waste flow remains behind scrap demand. This pushes up the marginal costs of scrap recovery and therefore mitigates the downward trends of the scrap prices.

The basic industries in the Netherlands have exploited their comparative advantages (geographical position at open water, close to important markets and relatively cheap energy) between 1970 and 1995. The market share of most Dutch basic industries increased between 1970 and 1995 and material production growth exceeded the West-European growth. Indeed, the primary and secondary aluminium production expanded twice as fast and the primary steel production also performed relatively well. On the other hand, secondary steel producers failed to catch up for new production technology. The Dutch paper industry shifted in the last decennia towards non-graphical paper and board production, which is primarily based on waste paper.

In the scenarios these specialisation trends are not continued because the explicit and implicit factors in the model that determines the competitive position of the Netherlands remain unchanged (see assumptions above) and the effect of the existing comparative advantages fades out. Therefore, Dutch primary production only expands a little more than the Western European primary production. Moreover, secondary production of the Netherlands lags behind the West-European development. The paper industry is already saturated with waste paper and so the share of secondary production improves only slightly. To a lesser degree, the already high recycling rate of the Dutch aluminium industry also restrains secondary production compared to Western Europe.

Energy productivity

Table 4.6 shows that the West European energy productivity increased substantially in the last decennia, with roughly 1.5% to 2.0% per year. This improvement partly originates in the increased share of energy-extensive secondary production. Historical data of petrochemical and phosphate industries show a deviation from the trend mentioned above, but these data are derived from less reliable sources.

In the scenario, the energy intensity of the basic industries declines roughly with 1.0 to 1.5% per year with the exception of the nitrogen industry and petrochemical industry. For the nitrogen industry the modest decline of .5% per year is caused by the large share of feedstock use. The result for the petrochemical industry is very dubious because of the quality of the underlying historical data. But even if the fuel efficiency increases at the average rate, the large share of feedstock use lowers the overall energy productivity improvement figure considerably. The modest increase of the energy productivity combined with the high growth rate of petrochemical industry challenges sustainability conditions seriously.

Table 4.6 *Energy productivity: total energy, fuels and electricity. Scenario: 2000-2020 and historical development: 1970-1995*

	fuel		electricity		total energy[a]	
	scenario	hist	scenario	hist	scenario	hist
	% change per year					
Western Europe						
steel	1.7	*3.9*	0.9	*–.1*	1	*1.9*
aluminium	0.4	*1.2*	1.5	*1.7*	1.2	*1.6*
petrochemical Blocks	0.3	–	–	–	0.2	*0.5*
paper	1.7	*2.1*	0.3	*0.1*	1.2	*1.5*
nitrogen	1.3	*4.2*	1.9	*5.3*	0.5	*2*
phosphates & potassium	1.4	4.5	1.4	5.7	1.4	4.7
Netherlands						
steel	1.4	*3.7*	0.5	*1.3*	0.5	*1.8*
aluminium	0.5	*1.4*	1.2	*2.3*	0.9	*1.9*
petrochemical Blocks	0.4	–	–	–	0.2	–
paper	2.3	*3*	1.5	*1*	2	*2.5*
nitrogen	1	*3.2*	2.3	*8.1*	0.3	*3.5*
phosphates	1.3	*4*	1.7	*8.1*	1.4	*4.4*

a] non-energy use is included
Historical period: 1970-1995, with exception of the petrochemical industry: 1980-1995

The decline of fuel intensity and electricity intensity is distributed unequally over industries. In line with historical trends, the improvement of the electricity productivity of the steel and paper industry lags behind the average. Analogously, the improvement of the fuel intensity of the aluminium and petrochemical industry remains far behind the average.

The energy productivity of Netherlands basic industry is more or less in line with the West-European development. The steel industry and paper industry are clear exceptions. The underachieving secondary steel production in the Netherlands depresses the overall energy productivity. The paper industry continues its relative favourable historical trend of large energy efficiency improvements.

Summary of the scenario results.

The scenario results show a considerable drop of the growth rate of material demand for OECD countries due to reduced intensities of use. The decline of material prices due to substantial cost price reductions does not prevent this development. Especially, scrap prices drop due to cost reducing technical progress and enhanced recovery policy. This supports secondary production. Comparative (dis)advantages of most materials remain unchanged. Accordingly, the material import and export flows and consequently material production, expand proportionally to material demand. The energy demand of most of the basic industries remains constant or decreases due to increasing energy efficiency and the increased penetration of secondary production. Plastic industry and to a lesser degree nitrogen industry are exceptions in this respect because of their large quantities of non-energy use.

4.3 Model Variants

This section analyses the sensitivity of the model outcomes to changes in exogenous economic variables, price variables, and process regulations. Five West-European and five comparable Netherlands variants on the base-line scenario are developed to illustrate the features of the model, its sensitivity and its usefulness for material markets analyses.

The model variants presented in this section are very partial due to the restricted scope of the model. Full-scale variants can be only derived if there are proper feed and feedback linkages to the macro economic and physical models mentioned in section 2.5. These linkages are not applied here. Moreover, the size of some variants may be implausible within the context of their own markets. However, the variations are aimed to illustrate the economic mechanisms of the model not to accomplish full-fledged economic analysis. So, the outcomes of the variants must be considered with prudence.

The variants and their points of interest are listed below:

1 *An economic production variant, leading to 25% more GDP in 2020 for Western Europe (1a) and for the Netherlands only (1b).*

   These variants show the impact of income growth on the demand for materials in Western Europe and the Netherlands. Moreover, they exemplify the effect of import leakage and export directed production of the exposed basic-industries in the Netherlands. This variant 1, only examens the production effects of economic growth and not the income (wage) effects.

2 *A real wage variant, leading to 25% higher real wage rate in the basic industries in 2020 in Western Europe (2a) and in the Netherlands only (2b).*

These variants illustrate the sensitivity of the competitive position of the West-European and Netherlands basic industries to a disadvantage in production costs. The variant only enters in the effects on the basic industries and does not concern about its feasibility with respect to the labour market. Moreover, the effects of this variant on the whole production structure and the consumption pattern in Western Europe or the Netherlands are ignored.

3 *An energy price tax, leading to a 100% increase of primary energy price in Western Europe (3a) and the Netherlands only (3b).*

These variants present the impact of changing energy prices on the energy demand in the basic industries by means of energy savings and international relocation of production capacity. In these variants it is assumed that the electricity price increases 30% as a consequence of the rise of primary energy prices (coal, oil and gas).

4 *A regulatory variant, which imposes an energy efficient technology as induced in variant 3a (4a) and 3b (4b).*

These variants illustrate the use of the model in the discussion about the effectiveness of regulatory policy versus price policy.

5 *A scrap price subsidy, leading to a recovery rate of 80% for Western Europe (5a) and for The Netherlands only (5b).*

These variants indicate the amount of scrap price subsidy that is required to achieve a recovery rate of 80%. Moreover, it indicates the related shifts on the scrap and material markets.

The remainder of this section presents the results of the variants:

Variant 1: *25% more national economic production in 2020.*

The impact of 25% more economic production in Western Europe (variant 1a) in the year 2020 on material demand is considerable, except for steel and fertilizers. Indeed, plastic demand increases by 50%. This underlines the key role of plastic in the industrialized economies due to its outstanding properties.

In the relatively closed Western European (OECD) economy, material production is in line with demand. A clear exception is aluminium. The aluminium import flows to Western Europe are substantial and in this variant the foreign suppliers meet a large part of increased demand. So, as table 4.7 shows, production growth is less buoyant than demand.

Table 4.7 Variant 1: The main effects of 25% more economic production in Western Europe and for the Netherlands only

	Steel	Alum.	Petr B	Plastic	Paper	Nitr.	Phos.
Western Europe (variant 1a)	(cumulative change %)						
Demand	10	26	40	52	21	11	5
Production	8	11	37	49	18	9	4
Primary	8	10	36	49	18		
Secondary	8	12	57	57	18		
Scrap recovery	6	14		41	19		
Scrap price	0	– 4		– 3	– 1		
Netherlands (variant 1b)							
Demand	9	35	20	52	27	8	3
Production	1	11	1	20	11	1	0
Primary	0	4	1	19	13		
Secondary	7	16	30	34	11		
Scrap recovery	7	28		41	22		
Scrap price	– 1	– 5		– 4	– 3		

The effects of increased economic production in the Netherlands on material demand (variant 1b) are more or less the same as those for Western Europe[12], with the exception of petrochemical building blocks, aluminium and paper.

The differences with respect to aluminium and paper stem from the higher demand elasticities to GDP for the Netherlands, which are based on the intra- and inter-sectoral

[12] The model ignores the developments on final product markets. These markets are described in the Athena model. The import leakage mentioned above also exists for final products and leads to a relative lower material demand in the exposed sectors. Therefore, one should expect a more modest demand increase for the Netherlands compared to Western Europe. Here, the Athena model is not used to take this effect into account.

structural changes in the past. Indeed, table 4.3 shows that historical aluminium demand in the Netherlands increased 6% per year against 3% per year for Western Europe, while economic growth was almost the same. This indicates that international specialisation in finished aluminium containing products has dominated the historical development of the Netherlands aluminium demand and affected the aggregate demand elasticity. It is quite possible however, that this international specialisation trend will not continue and the demand elasticity will gradually shift to a lower value. This example reveals the flaw that may arise if material demand is defined as the apparent material consumption (=production-export+import, see also 3.6).

The difference between West-European and the Dutch demand for petrochemical building blocks is rooted in the smaller increase of Dutch plastic production as a result of a substantial import leakage. More generally, the import leakages in the small open economy of the Netherlands cause a wider gap between demand and production growth[13] as for Western Europe.

The sluggish production increase of the Dutch basic industries relatively to the national material demand also creates excess supply of waste materials on the local scrap markets. This forces the scrap price to decline. Consequently, scrap import declines, scrap export increases and the recovery rate falls.

Variant 2: *25% higher real wage rate in basic industries in 2020.*

A 25% increase of the real wage rate in basic industries in Western Europe (variant 2a) deteriorates the international market position of the basic industries. This wage increase generates a modest cost price increase in the range of 3% to 6% for Western Europe and Netherlands, because of the small share of labour costs in the total production costs and the large substitution possibilities. However, this modest cost price increase induces a substantial loss on the foreign and domestic markets and leads to a production decline between 7% and 8%. The phosphate industry is a clear exception: phosphate production plunges 18% due to the relative openness of the phosphate market. Another exception is the relative small production loss of the sheltered West-European paper industry. Employment drops even more than production because labour productivity increases between 12% and18%.

If the wage rate increase is restricted to the Netherlands only, the production loss is in the range of 25% to 45%. The decline in production and the considerable gain in labour productivity lead all together to a fall of employment between 40% and 50% in the basic

[13] It should be remarked that it is quite possible that the import and export ratios for the Netherlands are overestimated because of transit material flows. In that case the import leakages are smaller than in the table above and consequently the domestic material production increases more.

industries. In the Netherlands, where each of the basic industries consists of just one or two plants a production loss of such proportions leads inevitably to reversed economies of scale and therefore higher production costs, further loss of market shares and ultimately to a shut down of capacity.

Table 4.8 Variant 2: The main effects of 25% higher wage rate in Western Europe and for the Netherlands only

	Steel	Alum.	Petr B	Paper	Nitr.	Phos.
Western Europe (variant 2a)	(cumulative change %)					
Export	– 20	– 9	– 20	– 3	– 15	– 25
Import	15	3	20	1	10	10
Production	– 7	– 8	– 8	– 3	– 7	– 18
Cost price	5	5	6	6	3	3
Employment	– 21	– 21	– 18	– 23	– 22	– 32
Labour productivity	15	14	12	17	16	18
Netherlands (variant 2b)						
Export	– 30	– 37	– 45	– 34	– 26	– 26
Import	17	4	– 11	6	13	16
Production	– 42	– 35	– 45	– 30	– 25	– 25
Cost price	6	6	6	8	3	4
Employment	– 50	– 45	– 51	– 39	– 39	– 39
Labour productivity	15	18	13	15	19	19

Variant 3: 100% increase of the primary energy price in Western Europe and the Netherlands only, as a result of an energy tax.

This variant shows the impact of changing energy prices on energy demand as a result of energy savings and international relocation of production capacity. A 100% levy is imposed on primary fuels (coal, oil, gas) in Western Europe (variant 3a). Consequently, the West-European electricity price increases about 30%.

Table 4.9 shows that West-European material demand is only little affected. The increased energy prices induce changes in the final product composition and material content of the final products. For the Netherlands, the material demand is mainly affected by changes in final product composition and by import substitution of finished products.

Table 4.9 *Variant 3: The main effects of an excess tax leading to a 100% increase of primary energy prices in Western Europe and for the Netherlands only. Feedstock is not charged*

	Steel	Alum.	Petr B	Paper	Nitr.	Phos.
Western Europe (variant 3a)	(cumulative change %)					
Demand	– 7	– 3	– 2	– 3	– 2	– 2
Cost Price: – primary	10	10	15	6	10	8
– secondary	5	3	4	3	–	–
Production: – primary	– 23	– 12	– 22	– 11	– 20	– 33
– secondary	– 7	– 5	– 8	3	–	–
Energy demand	– 30	– 33	– 32	– 33	– 30	– 50
Energy productivity	16	24	12	20	10	22
Netherlands (variant 3b)						
Demand	– 13	0	– 2	– 2	0	0
Cost Price: – primary	11	12	16	5	9	7
– secondary	6	3	4	2	–	–
Production: – primary	– 73	– 58	– 80	– 20	– 64	– 53
– secondary	– 22	– 20	– 24	– 10	–	–
Energy demand	– 77	– 64	– 83	– 29	– 67	– 65
Energy productivity	18	40	16	20	8	26

The energy tax generates a cost price increase of primary production in the range of 5 to 15%, and of 2 to 5% for secondary production. This deteriorates the competitiveness of the industry on the international markets. Furthermore, primary production is crowded out by secondary production. Consequently, West-European primary production drops about 20%, while secondary production declines by roughly 7%. There are some deviations from the general pattern: Firstly, the Western European aluminium industry is closely linked with nuclear power and therefore less sensitive to changes of energy prices. Paper producers traditionally have a relatively sheltered position on the international market, while in contrast the phosphate producers are very exposed.

The West-European energy demand of the basic industries roughly falls with 30% to 33% and exceeds the production decline due to the increased energy productivity. This increase originates in the improved energy efficiency and the shift from primary towards secondary production. The rise of the energy productivity of the petrochemical and nitrogen industry falls behind other materials because of the large proportion of feedstock use.

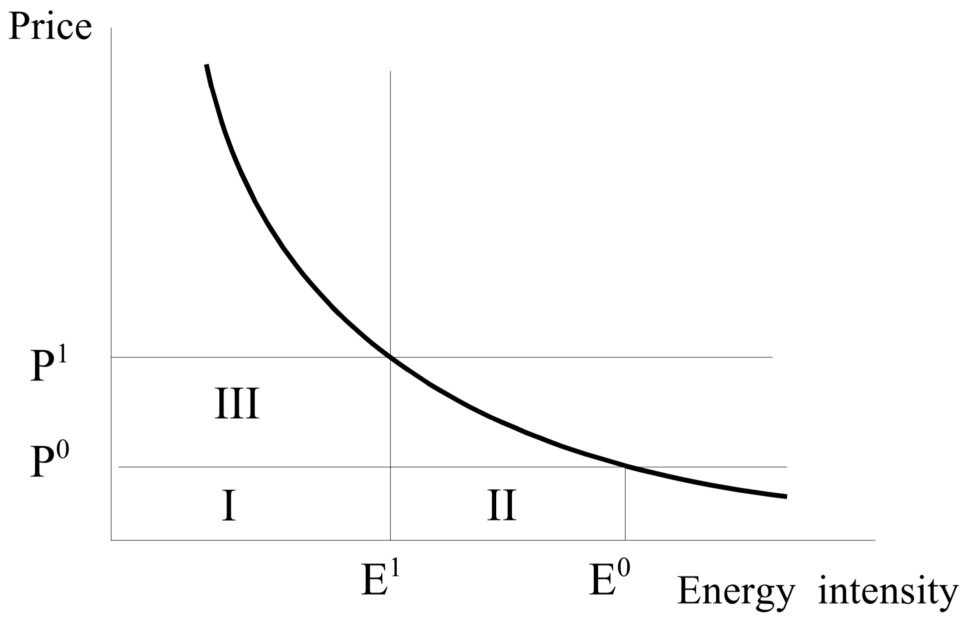
Approximately half the reduction in energy use arises from production reallocation towards outside Western Europe. Because material demand is only slightly affected, the reduction in domestic production must be compensated by foreign producers. However, these foreign producers have not improved their efficiency. The complete energy reduction of domestic and foreign users is just equal to the increased energy productivity of the domestic producers, which ranges from 10% to 25%.

As table 4.9 shows, the basic industries in the Netherlands are even more vulnerable to a non-concerted energy tax (variant 3b). The whole primary industry is wiped from the market, with the exception of the paper industry. A fall in production as shown in table 4.9 induces reversed economies of scale in these industries, which boosts the production costs further. Ultimately the industry will be shut down. To meet the hardly effected material demand, all primary products must be imported from foreign producers, that have not improved their efficiency. Consequently, a non-concerted (for the Netherlands only) energy tax mainly induces reallocation of basic industries instead of reduction of material demand.

Variant 4: A regulator imposes an energy efficient technology for the basic industry.
This variant starts from variant 3. Instead of a 100% energy price increase, the basic industries in Western Europe (variant 3a) or the Netherlands (variant 3b) are imposed to improve their specific energy efficiency to the level of variant 3. The main conclusion of variant 4 seems to suggest that an energy policy based on an imposed energy intensity affects the cost price of the producer much less than an energy tax policy such as variant 3. Consequently, the restrictive policy induces less international reallocation of production capacity. This difference in cost price effect between variant 3 and variant 4 can be explained by means of Figure 4.

The curve in figure 4 represents the relation between the optimal energy use per unit output of the firm and the price it has to pay for that energy. This relation shows a negative slope because it is profitable to invest in the more expensive energy saving options if the energy price increases.

Figure 4 Energy demand relation



If the energy price is P^0 the optimal energy use is E^0 and the energy costs amount to area I plus area II in figure 4. Now, if an energy tax is imposed as in variant 3 the energy costs per unit energy increases from price P^0 to price P^0+ tax= P^1. Consequently, the energy demand drops to E^1. The energy costs change in two ways: they decrease by area II due to the induced energy savings, but at the other hand they increase by area III because of the tax charges imposed on the remaining energy use. Furthermore, the capital costs (not shown in the figure) increase also.

If the firm is forced to comply with an energy intensity E^1 as in variant 4, the energy costs change only in one way: they decrease by area II due to energy savings.
The increased capital costs related to energy reduction to level E^1 are exactly the same as in variant 3. However, variant 4 differs from variant 3 because the remaining energy use E^1 is not charged and therefore the energy costs does not increase with area III.

Table 4.10 Variant 4, The main effects of an imposed energy efficient production technology in Western Europe and for the Netherlands only

	Steel	Alum.	Petr B	Paper	Nitr.	Phos.
Western Europe (variant 4a)	(cumulative change %)					
Demand	– 7	– 3	– 1	0	0	0
Cost Price: – primary	2	2	3	0	2	1
– secondary	1	1	1	0	–	–
Production: – primary	– 6	– 3	– 4	0	– 4	– 4
– secondary	– 5	– 3	– 1	1	–	–
Energy demand	– 17	– 24	– 16	– 17	– 15	– 25
Energy productivity	13	18	12	17	10	22
Netherlands (variant 4b)						
Demand	– 13	0	– 2	– 2	0	0
Cost Price: – primary	2	2	3	0	3	1
– secondary	1	1	1	0	–	–
Production: – primary	– 13	– 10	– 29	– 1	– 17	– 8
– secondary	– 12	– 6	– 1	– 1		
Energy demand	– 26	– 25	– 40	– 19	– 24	– 30
Energy productivity	15	19	16	17	8	24

Table 4.10 confirms that an imposed efficient technology in Western Europe can improve the firm's energy efficiency at the same rate as in variant 3a and a cost price increase of only one fifth. The West European primary producers lose therefore only a small part of their market to foreign producers and to secondary producers. Energy demand drops half as much as in variant 3a. The increase of the aggregate energy productivity is roughly 17.5% which only slightly lower than in variant 3a. The difference stems from the lower penetration of secondary production.

Non-concerted regulation in the Netherlands (variant 4b, table 4.10) shows more or less the same pattern. However, the impact of the increased production costs on the market share is at least twice as large as for Western Europe. Especially, the petrochemical and nitrogen industries still suffer a substantial loss in market shares. The energy productivity increases about 15% by the imposed technology. Energy demand decreases to a much larger extent due to import substitution. However, compared to the effect of variant 3b it is clear that for an open economy an efficiency regulation generates substantial less reallocation of production capacity that a undifferentiated energy tax.

The theoretical discussion and the model outcomes above suggests that in an open economy regulation policy should be preferred above tax policy. However, the results of the regulation variant 4 can also attained by a differentiated taxation in the sense that a part of the energy use is not charged. For instance, if in figure 4 the energy use (per unit output) is not charged up to level E^1 and all excess use is charged as in variant 3, the firm will reduce its energy use to E^1 at exactly the same costs as in variant 4.
In other words, the competitive position of the basic industries in a open economy deteriorates much less if high charges are imposed on the *marginal energy use* to improve the energy efficiency but also low charges on the *average energy use*. Indeed, if the charge on the marginal energy use is high enough it affects the production costs and the energy efficiency in exact the same way as a restriction on energy use.

Two comments should be given on this proposition:

- Figure 4 and STREAM are stylised models. They both ignore information and transaction costs, and heterogeneity of firms and production processes. In the real world, firms have different cost structures and face different savings options. A uniformly imposed energy intensity on all firms in a specific branch of industry may induce large inequalities in marginal costs between firms. This implies that some firms will not invest in relatively low cost energy saving options while other firms are forced to invest in relatively expensive saving options. Inequalities between firms may also arise if some uniform tranche of the energy demand in a branch of industry is not charged. Inequalities in marginal costs between firms can only avoided if the policy maker has full information about the cost structure and savings options of individual firms. Generally, this information can only be gathered at very high costs.
- If the energy policy is aimed to redress the external effects of the energy use, a restrictive policy or a differentiated tax policy is not appropriate. Indeed, these policies forsake *the polluter pays* principle. The external effect of every unit energy is the same and so energy should be charged uniformly. A levy on marginal energy use only undervalues the services of the natural environment. Consequently, the low average levy prevents the pass on of the environmental cost of energy use to the final consumers and therefore interferes with the essential change of the consumer pattern towards less energy intensive products. Furthermore, the marginal tax proceeds fail to meet the recuperation costs of the environment.

Variant 5: a recovery rate of 80% that is financed by the government.

This variant indicates the effort in terms of scrap price reduction that is required to achieve an 80% recovery rate in Western Europe (variant 5a) and in the Netherlands (variant 5b). It is presupposed that the costs of intensified material collection and recovery are financed by the government. The target is already met for steel and aluminium in the Netherlands. So, these cases are ignored.

Table 4.11 shows that the required scrap price reductions to reach 80% recovery in Western Europe (variant 5a) differ widely between materials. One reason for this is the initial distance to the target. For instance, West European steel scrap recovery has to increase by just 13% but plastic recovery by 85% to achieve its target. Another reason for different scrap price reductions is the degree of openness of the scrap and material markets. The West-European waste paper and paper markets are relatively closed (low price elasticities of import and export) and require a relatively large scrap price reduction to increase the waste paper recovery rate.

Table 4.11 Variant 5, The main effects of a subsidised scrap price to achieve a 80% recovery rate in Western Europe and for the Netherlands only.

	Steel	Alum.	Plastic[a]	Paper
Western Europe (variant 5a)	(cumulative change %)			
Recovery rate 2020 basis scenario	70%	55%	44%	60%
Scrap recovery	13	47	85	34
Scrap price	– 7	– 16	– 25	– 75
Cost price secondary production	– 2	– 7	–	– 20
Primary production	– 1	– 2	– 1	– 36
Secondary production	5	18	20	46
Energy demand	– 1	0	– 1	– 10
Netherlands (variant 5b)				
Recovery rate 2020 basis scenario	85%	80%	60%	73%
Scrap recovery	x	x	30	8
Scrap price	x	x	–6	– 2
Cost price secondary production	x	x	–	– 1
Primary production	x	x	– 1	– 1
Secondary production	x	x	24	3
Energy demand	x	x	0	2

a] Plastic recycling includes incineration of plastic.

If the markets are open, a scrap price reduction undercuts foreign scrap suppliers on the domestic and foreign markets. Moreover, the cost price of the secondary producers declines also and they will also increase their market share. So, in the case of exposed markets, the bulk of the additional recovered materials is directly and indirectly exported.

In the case of the relatively closed West-European paper market, the production reallocation between countries or regions is small. The only substitution possibility is between domestic primary and secondary production and between different materials. However, this substitution process is not so easy due to differences in quality between primary and secondary products of the same material and between different materials. Consequently, large differences in price are required to shift secondary demand to a level that can absorb the additional waste paper supply.

Summary of the variants

The variants illuminate the mechanisms that affect material flows in the economy. They indicate that high economic growth is still accompanied by a considerable increase of material demand. High economic growth for the Netherlands only has hardly any impact on the production of the export oriented national basic industries but it boosts material demand, and after consumption, scrap supply. This excess supply is met by increased secondary production and net scrap export.

Higher wage rates or energy prices in the basic industries have only a small impact on demand but large effects on the international allocation of the production capacity. Especially, if a cost increase is restricted to the Netherlands only the relocation effect is very large. Considerable labour and energy savings cannot prevent a rise in production costs and consequently a reallocation of productive capacity.

The variants also suggest that an internationally non-concerted energy price policy that increases the marginal energy costs and leaves the average energy costs unaffected may have a substantially lower international reallocation effect than a uniform energy tax. Consequently, only a fraction of the domestic and foreign consumers shift their demand from energy efficient domestic producers to less efficient bur cheaper foreign producers. In contrast, uniform price measures may reduce the energy use in the Netherlands very easily but merely export the environmental problems to other countries. Analogously, it is easy to increase the recovery rate in an open economy at the expense of the foreign recovery industry.

5. Conclusions

This paper presents a dynamic partial equilibrium model that allows CPB to analyse material flows in the West-European and Netherlands economy. The model provides a consistent framework for long-term material scenarios analysis and allows for some material related environmental policy analysis. The empirical investigation increased our knowledge about dematerialisation, recycling, international competition on the material and scrap markets, factor-substitution in the basic industries, long-run material scarcity, and the price-making process for raw materials, materials and scrap.

On the other hand, the parameter values of the identified model mechanisms are sometimes very uncertain as a consequence of the lack of data. This may affect the outcomes of the model seriously. Therefore, these outcomes should be used with prudence.

Moreover, the model has two serious limitations:

- The dematerialisation process is described by an aggregate reduced form relation on macroeconomic level. This approach does not allow a full examination of the factors and mechanisms behind the dematerialisation process: the factors and mechanisms that determine structural and technological change. Further investigation in this field is important for accurate interpretation of the development of historical material demand, reliable forecasting and the analysis of policy instruments for changing material demand. The research into the effect of structural change on material demand is continued in the research programme financed by NWO:'Materials Use and Spatial Scales in Industrial Metabolism' (MUSSIM), a joined research effort of various Netherlands institutes (IVM, RIVM, CPB) and universities (VU, WU).
- Technological progress is described as a smooth time dependant process. This suggests a predetermined development of technology in line with historical trends. It ignores however the huge R&D efforts of the companies and government and the economic and environmental effects of technological policy. Further investigation in this field enhances the understanding of the interrelationships between technological progress, economic growth and environment. The research into dynamics of technological change and environmental policy is continued in the research programme financed by NWO: 'Environmental Policy, Economic Reform and Endogenous Technology: a dynamic policy analysis' (PRET), a joined research effort of various Netherlands institutes (OCfEB, MERIT, CPB) and universities (KUB, TU).

The above mentioned research projects may address the shortcomings of the simplified statistical relationships between material demand and economic development with exogenous technological progress. The success of these research projects in terms of applicability for policy analysis depends very much on the availability of new relevant data sets. So, data collection remains of paramount importance.

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Theme A: Dematerialisation

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Appendix: The Model equations

1 World markets [14]

The economic variables in this block are defined in US dollars.
The material flows are defined in tons.

✱ *Material Demand:*
See also section 3.2.1.

Table A.1 Coefficients of the World material demand relations

material	region	α	β	γ	η	ϕ
steel	DC	0.01	1.1	1.2	– 0.075	– 0.2
	LDC	0.008	1.2	1	– 0.05	– 0.2
aluminium	DC	0.015	2.2	0.75	– 0.05	– 0.2
	LDC	0.02	2.5	0.25	– 0.1	– 0.2
plastic [see note]	DC	0.01	4	0	– 0.4	–
solvents	DC	0.01	2.25	0	– 0.3	–
paper	DC	0.01	1.25	0.5	– 0.025	– 0.2
nitrogen	DC	0.01	3.5	–	–	– 0.25
	LDC	0.01	3.25	–	–	– 0.25
phosphor	DC	0.01	2	–	–	– 0.25
	LDC	0.01	3	–	–	– 0.25
potassium	DC	0.01	2.5	–	–	– 0.25
	LDC	0.01	3	–	–	– 0.25

The petrochemical production is subdivided into the production of building blocks and the production raw plastics and solvents.

[14] The supply side of this part of the model has not been elaborated to full extent. Consequently, the model is not yet appropriate to analyse the competition between Developed Countries (DC's) and Less Developed Countries (LDC's). Moreover, the world block of the model lacks the vintage approach of the Western-European and the Netherlands block. As a matter of fact, the asymmetrical specification of the World block compared to Western-European block may induce a serious flaw of some outcomes of the model

material demand [m.1]: $$D = D_0 \times Y^{[\beta - \alpha \times t]} \times IY^{\gamma} \times [\frac{Pef}{Py}]^{\eta} \times [\frac{P}{Py}]^{\phi}$$

endogenous:	P [m.13]	material market price
exogenous:	Y	gross national product
		or: cereals production [fertilisers]
	IY	rate of investment (constant prices)
	Pef	energy price final users
	Py	general price level
	t	trend

✱ *Primary and secondary demand:*
See also section 3.2.2.

secondary [m.2]: $$\frac{Ds}{Dp} = \alpha \times S \times [\frac{Pe}{P}]^{\eta} \times [\frac{Pr}{P}]^{\epsilon}$$

with:

long run market share [m.2.a]: $$S = S(-1) + \sigma_e \times \ln[\frac{Pe}{P}] - \sigma_r \times \ln[\frac{Pr}{P}] + \sigma_0$$

endogenous:	P [m.13]	material price
	Pr [m.11]	scrap price
	Dp [m.3]	demand primary materials
exogenous:	Pe	energy prices basic industry
coefficients:	σ	

primary [m.3]: $$Dp = D - Ds$$

endogenous:	D [m.1]	material demand
	Ds [m.2]	demand secondary materials

Table A.2 Coefficients of the World primary en secondary production

material	region	α	η	ϵ	σe	σr	σo
steel	DC	0.1	0.5	– 1	0.025	– 0.05	0.01
	LDC	0.025	0.5	– 1	0.025	– 0.05	0.015
aluminium	DC	0.3	0.25	– 0.75	0.013	– 0.125	0
	LDC	0.725	0.5	– 0.25	–	–	–
plastic recycling	DC	0.025	–	– 1.5	–	–	–
plastic incineration	DC	0.075	–	– 2	–	–	–
paper	DC	0.16	0.4	– 1.5	0.01	– 0.01	0

Plastics[15]:

recycling [m.2.b]

$$Ds = \alpha \times [\frac{Pg}{Pr}]^{\epsilon} \times D_{plastic}$$

incineration [m.2.c]

$$Di = \alpha \times [\frac{Pe}{Pr}]^{\epsilon} \times Y^{\gamma(t)}$$

endogenous:	Ds [m.2.b]	scrap demand for recycling
	Di [m.2.c]	scrap demand for incineration
	Pr [m.11]	scrap price
	$D_{plastic}$	plastic demand
exogenous:	Pg	naphtha price
	Pe	energy price

15 There is little empirical information about the demand for secondary plastics. Two demand categories are distinguished: the use for recycling and the use for incineration. Provisional relations are used based on expert judgement and literature [Dennison,1993].

✱ *Demand for scrap and raw materials:*

Scrap [m4]: $Dr = cs \times Qs + (1 - cg) \times Qp$

Raw material [m5]: $Dg = (1 - cs) \times Qs + cg \times Qp$

endogenous:	Qs [m.7]	secondary production
	Qp [m.6]	primary production
Coefficients:	Cs, Cg	

✱ *Equilibrium:*

primary production [m.6]: $Qp = \frac{Dp}{Yldp}$

secondary product [m.7]: $Qs = \frac{Ds}{Ylds}$

endogenous:	Dp [m.3]	primary demand
	Ds [m.2]	secondary demand
exogenous:	Yldp, Ylds	yield factor

scrap production [m..8]: $Qr = Dr$

raw materials [m.9]: $Qg = Dg$

endogenous:	Dr [m.4]	scrap demand
	Dg [m.5]	raw material demand

✱ *Market prices, inverse supply* [16]*:*
See section 3.2.4.

Raw material price [m.10]:

$$\frac{Pg}{Py}=\frac{Pg(-1)}{Py(-1)}\times\lambda\times[\frac{U}{U(-1)}]^{\phi}\times(1+\beta\times Qg)$$

endogenous:	Qg [m.9]	raw material production
exogenous:	U	dollar exchange rate
	Py	national deflator

In contrast to ores, wood pulp is not an exhaustible resource. Its price depends on factor productivity and factor prices and as a substitute for fossil fuels it also depends on the energy price. The model uses the following simplified relation:

- Pulp price [m.10.a]:

$$\frac{Pg}{Py}=\lambda^{t}\times[\frac{Pe}{Py}]^{\beta}\times U^{\phi}$$

Table A.3 Coefficients World price relation for raw materials

material	λ	ϕ	β
iron ore	0.98	– 0.5	0.015
bauxite	0.985	– 0.5	0.00025
naphtha		exogenous	
pulp	0.995	– 0.5	0.15
natural gaz		exogenous	
phosphate rock	0.985	– 0.75	0.0001
potassium	0.985	– 0.25	0.0001

Scrap price [m.11]:

$$\frac{Pr}{Py}=\alpha\times\lambda^{t}\times[1-\gamma\ln(1-\frac{Qr}{W})]$$

[16] The petrochemical industry draws its raw material (feedstock) from the natural oil resources. The crude oil prices are exogenous in this model. Furthermore, the paper industry is based on wood which is a renewable resource. The main feature of the wood price is its relation to the energy price, partly as an important input factor in forestry and pulp production and partly as a substitute for fossil fuels.

endogenous:	W [m.12]	waste
	Qr [m.8]	recovery

Table A.4 Coefficients of the World scrap price relation

material	region	λ	γ
steel	DC	0.985	1
	LDC	0.98	1
aluminium	DC	0.9925	1
	LDC	0.995	1
plastic	DC	0.975	1
paper	DC	0.98	1

The value of γ has been derived from bottom up information from "Recycling Hulp" TNO.
Source: J. van Dam and W. Blom, RIVM, 1998.

Waste [m.12]:

$$W = \sum_{j}^{n} g_j \times D(t-j)$$

endogenous:	D [m.1]	material demand
coefficients:	g	discard rate

Material price [m.13]:

$$\frac{P}{Py} = \alpha \times \lambda^t \times [\frac{Pe}{Py}]^{\eta} \times [\frac{D}{D(-1)}]^{\delta} \times [\frac{U}{U(-1)}]^{\phi} + \frac{Dg}{D} \times \frac{Pg}{Py} + \frac{Dr}{D} \times \frac{Pr}{Py}$$

endogenous:	D [m.1], Dg [m.5] , Dr [m.4]	demand materials, raw materials and scrap
	Pg [m.10], Pr [m.11]	price raw materials and scrap
exogenous:	Pe	energy price basic industry
	U	dollar exchange rate

Table A.5 Coefficients world material price equation

material	λ	η	δ	ϕ
steel	0.9875	0.2	0.4	− 0.4
aluminium	0.995	0.25	−	− 0.5
plastic	0.9925	0.6	−	− 0.5
paper	0.9875	0.2	−	− 0.2
nitrogen	0.99	0.5	−	− 5
phosphates	0.99	0.6	−	− 0.5
potassium	0.99	0.35	−	− 0.5

2 Western Europe

✱ *Material demand:*
See also section 3.2.1.

Material demand [e.1]:

$$D = D_0 \times Y^{[\beta - \alpha \times t]} \times IY^{\gamma} \times [\frac{Pe}{Py}]^{\eta} \times [\frac{P*}{Py}]^{\phi}$$

endogenous:	P*[m..13]	world market price
exogenous:	Y	gross national product
	IY	rate of investment (constant prices)
	Pef	energy price final users
	Py	general price level

Table A.6 Coefficients of the West-European material demand equations

material	α	β	γ	η	ϕ
steel	0.01	0.9	0.75	– 0.1	– 0.2
aluminium	0.01	2.05	0	– 0.05	– 0.2
plastic [see note]	0.015	4	0	– 0.5	–
solvents	0.0075	2.25	0	– 0.3	–
paper	0.0125	1.1	0.4	– 0.05	– 0.075
nitrogen	0.01	1.75	–	–	– 0.5
phosphates	0.01	1.1	–	–	– 0.5
potassium	0.01	0.8	–	–	– 0.25

The petrochemical production is divided into the production of building blocks (e.g. ethylene) and the production of raw plastics(polymers) and solvents.

✱ *International material trade*
See also section 3.2.5.

Table A.7 Coefficients of the West-European trade equations

Trade	material	α	β	σ	σ_0
Export	steel	0.065	– 4	– 0.05	0
	aluminium	0.074	– 2	– 0.04	0
	building blocks	0.045	– 5	– 0.01	0
	plastic	0.025	– 5	– 0.01	0
	paper	0.025	– 2	– 0.01	0.005
	nitrogen	0.125	– 4	– 0.1	0.015
	phosphate	0.0075	– 4	– 0.1	0.0075
	potassium	0.15	– 4	– 0.1	0.03
Import	steel	0.035	2	–	–
	aluminium	0.4	2	–	–
	building blocks	0.06	4	–	–
	plastic	0.05	2	–	–
	paper	0.06	2	–	–
	nitrogen	0.075	4	–	–
	phosphate	0.09	4	–	–
	potassium	0.11	4	–	–

Export [e.2]:

$$X = \alpha_x \times [\frac{Pq}{P*}]^{\beta_x} \times S \times D*$$

Import [e.3]:

$$M = \alpha_m \times [\frac{Pq}{P*}]^{\beta_m} \times S^{-1} \times D$$

Long run market share [e.3.a]:

$$S = S(-1) + \sigma \times \ln(\frac{Pq}{P*}) + \sigma_0$$

endogenous:	Pq [e.24]	material cost price
	P* [m..13]	international material market price
	D* [m.1]	international material demand

	D [e.1]	material demand
	S [e.3.a]	long run market share

✱ *Primary and secondary demand:*
See also section 3.2.2.

Secondary [e.4]:

$$\frac{Ds}{Dp} = \alpha \times Sps \times [\frac{Pqp}{Pqs}]^{\beta} \times IY^{\gamma}$$

Long run market share [e.4.a]:

$$Sps = Sps(-1) + \sigma \times \ln(\frac{Pqp}{Pqs}) + \sigma_0$$

Primary [e.5]:

$$Dp = D - Ds$$

exogenous:	IY	rate of investment (constant prices)
endogenous:	Pqp, Pqs [e.24]	cost price primary and secondary production
	D [e.1]	total material demand
	Sps[e.4.a]	long run share secondary production

Table A.8.1 Coefficients West-European primary en secondary demand

material	α	β	γ	σ	σ_0
steel	0.125	3	0	0.1	0
aluminium	0.35	2	2	0.075	0
paper	0.375	4	0	0.1	0

✱ *Demand for scrap and raw materials:*

Scrap [e.6]:

$$Dr = cs \times Qs + (1 - cg) \times Qp$$

Raw material [e.7]:

$$Dg = (1 - cs) \times Qs + cg \times Qp$$

endogenous:	Qs, Qp [e.11]	secondary and primary production
coefficients:	cs,cg	

- Plastic[17]*:*

feedstock recycling [e.7.a] $$Drf = \alpha \times [\frac{Pg}{Pr}]^{\beta} \times Q_{building\ blocks}$$

mechanical recycling [e.7.b] $$Drm = \alpha \times [\frac{P_{plastic}}{Pr}]^{\beta} \times D_{plastic}$$

incineration [e.7.c] $$Dri = \alpha \times [\frac{Pe}{Pr}]^{\beta} \times Y^{\gamma(t)}$$

Table A.8.2 Coefficients West-European secondary plastic demand

process	α	β
feedstock recycling	0.0025	2
mechanical recycling	0.035	2
incineration	0.075	4

plastic scrap demand [e.7.d] $$Dr = Drf + Drm + Dri$$

feedstock demand [e.7.e] $$Dg = Q - Drf - Drm$$

endogenous:	Drf [e.7.a]	feedstock recycling
	Drs [e.7.b]	mechanical recycling
	Dri [e.2.c]	scrap demand for incineration
	Dr [e.7.d]	plastic scrap demand
	Dg [e.7.e]	virgin feedstock demand
	Pr [e.25]	scrap price
	$Q_{\text{building blocks}}$	feedstock demand
	D_{plastic}	plastic demand
exogenous:	Pg	naphtha price

[17] There is little empirical information about the demand for secondary plastics. Until more empirical information is gathered, a more simple approach is used for plastic recycling. Three demand categories are distinguished: the use for feedstock recycling, the use for mechanical recycling and the use for incineration. Provisional relations, based on expert judgement and literature [Shell,1995] describe these demand categories.

$P_{plastic}$	price raw plastic
Pe	energy price

✱ *International trade of scrap and raw materials[18]:*
See also section 3.2.5.

Export [e.8]:

$$Xr = \alpha_x \times \lambda_x{}^t \times [\frac{Pr}{Pr^*}]^{\beta_x} \times Dr^*$$

Import [e.9]:

$$Mr = \alpha_m \times \lambda_m{}^t \times [\frac{Pr^*}{Pr}]^{\beta_m} \times Ds$$

endogenous:	Dr* [m.4]	international scrap demand
	Dr [e.6]	regional scrap demand
	Pr* [m.11]	international scrap price
	Pr [e.25]	regional scrap price

Table A.9 Coefficients of West European scrap trade equations

		α	β	λ
Export	steel	0.0075	– 4	1
	aluminium	0.0075	– 4	1.01
	plastic	0.008	– 4	1
	paper	0.00055	– 1.5	1.015
Import	steel	0.045	2	1
	aluminium	0.05	2	1.01
	plastic	0.05	2	1
	paper	0.025	1	1.015

[18] West-European import and export for scrap data are not available in a consolidated form. In other words, they also include the intra regional trade. It is therefore difficult to find a affect of regional scrap price differences on these import and export flows.

Raw material import [e.10]: $Mg = Dg + Xg - Qg$

endogenous:	Dg [e.7]	– raw material demand
exogenous:	Xg	– export of raw materials
	Qg	– production of raw materials

✱ *Equilibrium:*

Raw materials [e.10]: $Qg = Dg + Xg - Mg$

endogenous:	Dg [e.7]	raw material demand
exogenous:	Xg	export
	Qg	production

Materials [e.11.]: $Q_i = \frac{D_i + X_i - M_i}{Yld_i}$

for process i

endogenous:	D [e.1]	material demand
	X [e.2]	export
	M [e.3]	import
exogenous:	Yld	yield factor

with:

[e.11.a]: $X_i = D*_i \times \frac{X}{D*}$

[e.11.b]: $M_i = D_i \times \frac{M}{D}$

for process i

endogenous:	D [e.1,e.4,e.5]	regional demand
	D* [m.1, m.2, m.3]	international demand
	X [e.2]	export demand
	M [e.3]	import demand

Scrap [e.12]: $Qr = Dr + Xr - Mr$

endogenous:	Dr [e.6]	scrap demand
	Xr [e.8]	export
	Mr [e.9]	import

✱ *Material supply*[19] *and factor demand:*
See also section 3.2.3.

Capacity [e.13]:

$$C_i = (1 - AF_i) \times C_i(-1) + dC_i$$

process i

endogenous:	dC [e.15]	capacity new vintage
	AF [e.16]	scrap rate

Factor demand [e.14] :

$$Z_{i,j} = (1 - AF_i) \times Z_{i,j}(-1) + dZ_{i,j}$$

process i en factor j

endogenous:	dZ [e.19]	factor demand new vintage
	AF[e.16]	scrap rate

Capacity expansion [e.15]:

$$dC_i = Q_i(-1) \times [AF_i + .\alpha \times (E(\Pi_i) - RR) + \beta \times E(D\%)]$$

and:

Scr*ap rate [e.16]:*

$$AF_i = af_i^* \times [\frac{Q_i}{C_i}]^\delta \times [\frac{Pq_i}{Pqn_i}]^\gamma$$

[19] The West-European production capacity for materials is an aggregate of previous yearly investments, the so called vintages. These vintages are characterised by entrepreneur's perception of the economical conditions at the moment of installation. After installation the characteristics of the vintage become more or less fixed and they remain a part of the overall capacity until the vintage is scrapped. The investment specification adheres to the neo-Keynesian tradition. Additionally to the profit principle it also allows for the acceleration-principle (demand growth) as determinating factor of investments. The scrap rate covers the process of technical deterioration and process of economic obsolescence in terms of national and international demand and competition and in terms of profitability compared to new vintages.

process i

endogenous:	E(π): [e.17]	expected profit
	E(D%): [e18];	expected demand
	Q: [e.11];	production
	C: [e.13].	capacity
	Pqn:[e.23]	product price new vintage
	Pq: [e24]	average product price
exogenous:	RR	real interest

Table A.10 Coefficients of investment equations for Western-Europe

material	α	β	γ	δ	af*
steel	0.25	0.8	4	2	0.1
aluminium	0.25	1	4	2	0.1
petrochemical building blocks	0.25	0.85	4	2	0.1
plastic	0.25	0.85	4	2	0.1
paper	0.25	0.8	4	2	0.1
nitrogen	0.25	0.8	4	2	0.1
phosphates	0.25	0.8	4	2	0.1
potassium	0.25	0.8	4	2	0.1

Expectations are formed in an adaptive way:

Expected profit rate [e.17]:

$$E(\Pi_i) = \lambda \times E(\Pi_i(-1)) + (1-\lambda) \times [\frac{P}{Pqn_i} - 1]$$

Expected demand growth [e.18]:

$$E(D\%) = \lambda \times E(D\%(-1)) + (1-\lambda) \times [\frac{D}{D(-1)} - 1]$$

process i

endogenous:	P:m.8	Market price
	D:e.1	Demand
	Pqn: e17.	Cost price

Additional factor demand [e.19]: $dZ_{i,j} = Fn_{i,j} \times dC_{i,j}$

process i and factor j

endogenous :	Fn [e.22]	factor intensity
	dC [e.15]	gross capacity expansion

Translog cost function[20]*:*

Cost price [e.20] : $$\ln(Pc_i) = \sum_j a_{i,j} \times \ln(Px_j) + \frac{1}{2} \times \sum_j \sum_h b_{i,j,h} \times \ln(Px_j) \times \ln(Px_h)$$

process i and factor j and h

exogenous	Px	factor price

Factor shares [e.21]: $$S_{i,j} = a_{i,j} + \sum_j b_{i,j} \times \ln(Px_j)$$

process i and factor j

Substitution elasticities [e.20.a]: $$\sigma_{i,j,h} = \frac{b_{i,j,h} - \delta_{j,h} \times S_j}{S_{i,j} \times S_{i,h}} + 1$$

with: $\delta = 0$ if $j \neq h$ and $\delta = 1$ if $j=h$

process i and factor j and h

Price elasticity of factor demand [e.20.b]: $\eta_{i,j,h} = S_h \times \sigma_{i,j,h}$

Specific factor use [e.22]: $$Fn_{i,j} = S_{i,j} \times \frac{Pc_i \;/\; Fm_i}{Px_j}$$

process i en factor j

endogenous:	Pc:[e.20]	cost price
	S: [e.21]	cost share
trend:	Fm	material intensity to economic production

[20] The potential for microeconomic substitution among factor inputs is summarized by the *partial substitution elasticities*. These can be obtained from the relationship among the cost function parameters and the factor shares. [Uzawa, 1962]

Table A.11 Own price elasticities of (substitutable) factor demand in primary and secondary material production

material	Labour	Capital	Coal	Electricity	Oil	Gaz
primary						
steel	– 0.7	– 0.45	– 1.15	– 0.9	– 4.5	– 1.95
aluminium	– 0.8	– 0.85	– 1	– 0.8	– 1	– 1
building blocks	– 0.7	– 0.6	–	–	– 0.6	–
plastics	– 0.5	– 0.6	–	–	– 1	–
paper	– 1.5	– 0.7	– 1	– 1	– 1	– 0.6
nitrogen	– 1.1	– 0.5	–	– 1	–	– 0.9
phosphate	– 1	– 0.5	–	– 1	–	– 0.95
potassium	– 1	– 0.5	–	– 1	–	– 0.9
secondary						
steel	– 0.7	– 0.55	–	– 0.9	– 1	– 1
aluminium	– 0.8	– 0.65	–	– 1	– 0.95	– 1
paper	– 1.5	– 0.7	– 1	– 1	– 1	– 0.6

The cost price per physical unit of production:

Cost price/ton new vintage [e.23]:

$$Pqn_i = \frac{Pc_i}{Fm_i} + \sum_h Pm_{i,h}$$

process i and fixed input h

endogenous:	Pc [e.20]	economic cost price
	Pg [m.10]; Pr [e.25]	material price: raw material or scrap or non-substitutable energy
trend:	Fm	material intensity to economic production

From definition the cost price per physical unit production is also:

Cost price new vintage [e.23]:

$$Pqn_i = \sum_j Pz_j \times \frac{dZ_{i,j}}{dC_i} + \sum_h Pm_{i,h}$$

process i, input j and fixed input h

endogenous:	dZ	input new vintage

	dC	capacity new vintage
exogenous	Pz	input prices

The cost price per physical unit production on the aggregate level is:

Cost price [e.24]:

$$Pq_i = \sum_j Pz_j \times \frac{Z_{i,j}}{Q_i} + \sum_h Pm_h$$

process i, input j and fixed input h

endogenous:	Z:[e.14]	input
	Q:[e.11]	output
	Pm [m.10][e.25]	prices fixed inputs

✱ *Scrap supply*

See also section 3.2.4.

Scrap price [e.25]:

$$\frac{Pr}{Py} = \alpha \times \lambda^t \times [1 - \gamma \ln(1 - \frac{Qr}{W})]$$

endogenous:	Qr: [e.12]	recovered material
	W [e.26]	waste material

Waste supply [e.26]:

$$W = \sum_j^n g_j \times D(t-j)$$

endogenous:	D	material demand
coefficients:	g	discard rate

Table A.12 Coefficients of the scrap price equation of Western Europe

Material	λ	γ
Steel	0.985	1
Aluminium	0.995	1
Plastic	0.975	1
Paper	0.98	1

The value of γ is derived from bottom up information from "Recycling Hulp" TNO.
Source: J. van Dam and W. Blom, 1998, RIVM

3 The Netherlands

Model Equations:

✱ *Material demand*[21]
See also section 3.2.1.

Material demand [n.1.a]: $D = Ys^{[\beta - \alpha \times t]} \times IY^{\gamma} \times [\frac{Pef}{Py}]^{\eta} \times [\frac{P*}{Py}]^{\phi}$

with:

Material re-weighed economic production [n.1.b]: $Ys = \sum_n d_n^0 \times Y_n$

sector: n		
endogenous:	P*[m.13]	– material market price
exogenous:	Yn	– gross sectoral production
	IY	– macro rate of investment (constant prices)
	Pef	– energy price final users
	Py	– general price level
coefficients	d_n	[source CBS 1990]

This specification does not apply GDP as an explanatory variable but a material re-weighed indicator of sectoral gross production. Table A.13 shows that this sectoral[22] breakdown of GDP does not contribute much to the explanation of the de-linking process. The de-linking parameter α and the shift-parameters (γ,η,ϕ) have hardly other values as in the aggregate specification.

[21] It should be mentioned, that for a small country the apparent material consumption as registered in the data might be biassed, because it does not take into account the final product incorporated materials from import and export flows. A considerable difference with real material demand may arise.

[22] Agriculture, Food industry, Wood&Building materials, Textile, Paper&Graphical industry, Chemical industry, Mining, Metal products, Machine-industry, Electronic industry, Car industry, Construction, Public Utilities, Services industry. Source sectoral demand 1990 (d_n): S. de Boer, R.E.H. van der Holst, W. Tebbens, RPh. van der Wal,'Iron, steel and zinc in the Netherlands economy, 1990, CBS, September 1994, table 5 en 6 rrow 3 t/m 10.

Table A.13 Coefficients Netherlands material demand equations

material	α	β	γ	η	ϕ
steel	0.01	0.7	0.75	– 0.2	– 0.2
aluminium	0.01	3.1	0	– 0.05	– 0.2
plastic	0.01	3.8	0	–	– 0.9
solvents	0.015	2.25	0	–	– 0.5
paper	0.0125	1.75	0	– 0.025	– 0.2
nitrogen	0.015	0.5	0	–	– 0.5
phosphates	0.025	0	0	–	– 0.5
potassium	0.025	0	0	–	– 0.5

✱ *Primary and secondary demand*[23]

See also section 3.2.2. and table A.8 (Western Europe model block)

Secondary [n.2]:

$$\frac{Ds}{Dp} = \alpha \times Sps \times [\frac{Pdp}{Pds}]^{\beta} * IY^{\gamma}$$

Long run market share [n.2.a]:

$$Sps = Sps(-1) + \sigma \times \ln(\frac{Pdp}{Pds}) + \sigma_0$$

Primary [n.3]:

$$Dp = D - Ds$$

exogenous:	IY	national investment rate(constant price)
endogenous:	Pds, Pdp [n.4]	purchase prices
	D [n.1]	total material demand
	Sps[n.2.a]	long run share of secondary demand

Purchase price [n.4]:

$$Pd_i = Pq_i \times \frac{D_i - M_i}{D_i} + Pq*_i \times \frac{M_i}{D_i}$$

[23] There are no time series about the partition of the national material demand into primary and secondary demand. Therefore the model assumes that the price effects are the same as in Western Europe.

process i

endogenous:	D: [n.2],[n.3]	– material demand
	M: [n.6]	– material import
	Pq: [n.15]	– cost price domestic production
	Pq*:[e.24]	– cost price foreign production

✱ *International material trade*

See also section 3.2.5.

Export [n.5]:

$$X_i = \alpha \times S \times [\frac{Pq_i}{Pq*_i}]^{\beta} \times D*_i$$

process i

endogenous:	D*:[e.1]	international material demand
	Pq: [n.15]	cost price domestic material producers//f
	Pq*:[e.24]	cost price foreign material producers

Import [n.6]:

$$\frac{M_i}{D_i - M_i} = \alpha \times S \times [\frac{Pq_i}{Pq*_i}]^{\beta} \times D_i$$

Long run market share [e.5.a]:

$$Si = Si(-1) + \sigma_i \times \ln(\frac{Pq_i}{Pq_i^*}) + \sigma_{0i}$$

Table A14 shows the value of the coefficients.

✱ *Demand for scrap and raw materials*

Scrap [n.7]: $Dr = cs \times Qs + (1 - cg) \times Qp$

Raw material [n.8]: $Dg = (1 - cs) \times Qs + cg \times Qp$

endogenous:	Qs, Qp [n.11]	primary and secondary demand
coefficients[24]:	cs, cg	

For plastics the same alternative approach is applied as for Western Europe [see e.7.]

[24] For primary steel these coefficients are a function of the penetration of the continuous casting process and the relative scrap price.

Table A.14 Coefficients of the Netherlands material trade equations

Material		α	β	σ	σ_0
Export					
steel	– primary	0.015	– 7.5	– 0.05	0
	– secondary	0.01	– 4	– 0.025	0
aluminium	– primary	0	– 8	– 0.05	0
	– secondary	0.02	– 8	– 0.05	0
plastic	– building blocks	0.175	– 10	– 0.1	0
	– polymers	0.07	– 8	– 0.01	0
paper	– primary	0.025	– 8	–	–
	– secondary	0.025	– 8	–	–
nitrogen		0.065	– 10	– 0.1	0
phosphate		0.032	– 8	– 0.05	– 0.005
Import					
steel	– primary	5.75	4		
	– secondary	2	2		
aluminium	– primary	3	6		
	– secondary	2	6		
plastic	– building blocks	5	8		
	– polymers	1.15	4		
paper	– primary	0.8	5		
	– secondary	0.8	5		
nitrogen		0.1	8		
phosphate		1.6	10		

✱ *International scrap and raw material trade*

See also section 3.2.5.

Table A.15 Coefficients scrap trade equations of the Netherlands

Trade	*Material*	α	β	λ
Export	steel	0.0125	– 6	1
	aluminium	0.0075	– 0.6	n.a.
	plastic		not specified	
	paper	0.06	– 4	–
Import	steel	0.1	2	1
	aluminium	0.125	4	1.01
	plastic		not specified	
	paper	0.25	4	–

Export scrap [n.9]:

$$Xr = \alpha_x \times \lambda^t \times [\frac{Pr}{Pr*}]^{\beta_x} \times Dr*$$

Import scrap [n.10]:

$$Mr = \alpha_m \times \lambda^t \times [\frac{Pr}{Pr*}]^{\beta_m} \times Dr$$

endogenous:

Dr*:[e.6]	international scrap demand
Dr:[n.7]	national scrap demand
Pr*:[e.25]	international scrap price
Pr:[n.16]	national scrap price

✱ *Equilibrium:*

Material production [n.11]: $Q_i = D_i + X_i - M_i$

process i.
endogenous:

D: [n.2], [n.3]	demand
X: [n.5]	export
M: [n.6]	import

Recycling [n.12]: $Qr = Ds + Xs - Ms$

endogenous:

Dr:[n.7]	scrap demand
Xr:[n.9]	scrap export
Mr:[n.10]	scrap import

Raw materials [n.13]: $Mg = Dg + Xg - Qg$

endogenous:

Dg [n.8]	mineral demand

exogenous:

Qg	mineral production
Xg	mineral export

✱ *Material supply:*

This part of the model is similar to the West-European supply block. The main endogenous variables are the capacity (C, [n.14]) and the material cost price (Pq, [n.15]). In fact, the investment behaviour and the set of attainable production technologies are assumed to be the same. Therefore, the Netherlands material supply block uses the same coefficient values as shown in table A.10 and A.11.

(see Western Europe model block).

✱ *Scrap supply:*

See also section 3.2.4.

Scrap price [n.16]: $$\frac{Pr}{Py} = \alpha \times \lambda^t \times [1 - \gamma \ln(1 - \frac{Qr}{W})]$$

Waste [n.17]: $$W = \sum_j^n g_j \times D(t-j)$$

endogenous:

Qr: [n.12]	recovery production
D [n.1]	material demand
Px	input prices

Table A.16 *Coefficients scrap price equation of the Netherlands*

Material	λ	γ
Steel	0.985	1
Aluminium	0.995	1
Plastic	0.9825	1
Paper	0.98	1

Abstract

This paper presents STREAM, a partial equilibrium model for seven bulk materials: steel, aluminium, plastic, paper, nitrogen, phosphate and potassium. The model describes the dynamic relations between physical and monetary flows in a chain of activities: extraction, production, consumption, recycling and disposing. These activities are related to each other by supply and demand of producers and consumers for products, materials and scrap. Supply and demand forces determine the market prices and material flows. The model includes simple forms of forward cost linkages and backward demand linkages and it encompasses three substitution mechanisms: input substitution, material substitution and spatial substitution.

The model provides a consistent framework for material scenarios and related environmental policy analysis for Western-Europe and the Netherlands within an global economic context. The empirical validation of the model is based on time-series and on technical coefficients derived from literature. The empirical investigation increased our knowledge about predominant economic factors, mechanisms and parameters that determine the material flows, especially in the field of:

- Dematerialisation trends and the relation to GDP, energy prices and the material price.
- Recycling trends and the relation to the prices of scrap, energy and virgin materials.
- Input substitution in material production and the relation to energy demand.
- Market and cost prices of raw materials, materials and scrap.
- The sensitivity of West-European and Dutch trade flows to price differences with foreign competitors.

This paper also presents a baseline scenario for materials until 2020, two economic variants and three environmental policy variants for Western Europe and the Netherlands each to illustrate the applicability of the model in scenario and policy analysis.

Featuring the historical economic and social trends and mechanisms, future demand for most materials increases very modestly. Taking into account a considerable energy productivity gain, energy demand remains more or less constant. Plastic is a clear exception: plastic demand remains in line with economic growth and plastic industry only gains a small energy productivity increase due to the large share of feedstock demand. The policy variants show among other things that an internationally non-concerted energy price policy that increases the marginal energy costs and leaves the average energy costs unaffected may have a substantially lower international displacement effect than a uniform energy tax. Consequently, only a fraction of the

domestic and foreign consumers shift their demand from energy efficient domestic producers to less efficient but cheaper foreign producers.

The policy variants show among other things that in an open economy a unilateral efficient regulatory policy is more effective than a unilateral price policy.