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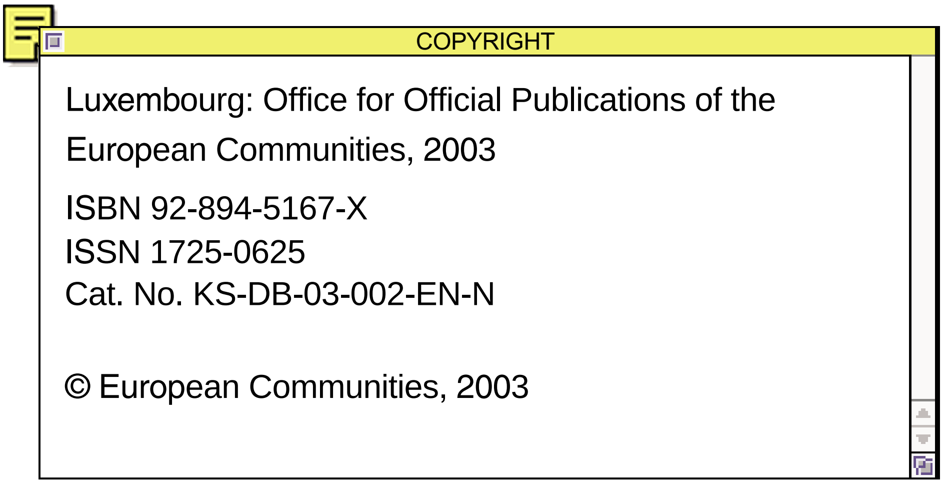

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DECOMPOSITION ANALYSIS OF CARBON DIOXIDE EMISSION CHANGES IN GERMANY - CONCEPTUAL FRAMEWORK AND EMPIRICAL RESULTS

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February 2003

Table of contents

PART I: THEORETICAL CONSIDERATIONS 11

PART II: EMPIRICAL RESULTS 19

Preface

Eurostat is actively developing environmental accounts linked to national accounts. In many areas of environmental accounting we have already developed frameworks and statistical manuals and published numerical results (see overleaf for a list of Eurostat publications in the field of environmental accounting).

The Statistical Offices of many Member States are now regularly compiling environmental accounts data sets, for example air emission accounts in a NAMEA format (NAMEA stands for National Accounts Matrix including Environmental Accounts). Analytical uses of these data sets are becoming increasingly widespread.

In several Member States standard analysis is already an integral part of environmental accounts work. Such analysis is often based on input-output techniques and the results are published together with more basic indicators derived from the environmental accounts. Standard analysis includes the allocation of (indirect) emissions to final uses, analysis of emissions that are embedded in international trade flows, and structural decomposition analysis.

This publication presents the results of analytical and methodological work on decomposition analysis undertaken by the Environmental Economic Accounting division of the German Federal Statistical Office. The publication presents the principles of decomposition analysis and shows the impact of methodological choices on the results.

Eurostat encourages the Member States to publish these analytical results and to work together in developing and testing methods and comparing results. EU-wide recommendations for standard methods for analysis could then be developed.

Brian Newson
Head of Unit B1
National accounts methodology,
statistics of own resources

Eurostat Environmental Accounting publications

Official publications *(available at www.europa.eu.int/comm/eurostat)*

- Accounts for Recreational and Environmental Functions of Forests – Results of Pilot Applications (2002)
- Natural Resource Accounts for Forests – 1999 Data (2002)
- Environmental Protection Expenditure Accounts – Results of Pilot Applications (2002)
- Water Accounts – Results of Pilot Studies (2002)
- Material Use in the European Union 1980-2000: Indicators and Analysis (2002)
- Environmental Taxes in the EU 1980-1999 – Statistics in Focus Theme 2 – 29/2002
- SERIEE Environmental Protection Expenditure Accounts – Compilation Guide (2002)
- Natural Resource Accounts for Oil and Gas – 1980-2000 (2002)
- NAMEAs for air emissions – Results of Pilot Studies (2001)
- Environmental Taxes – A Statistical Guide (2001)
- Economy-wide Material Flow Accounts and derived Indicators – A Methodological Guide (2001)
- Accounts for Subsoil Assets – Results of Pilot Studies in European Countries (2000)
- Valuation of European Forests - Results of IEEAF Test Applications (2000)
- Environmental Taxes in the EU – Statistics in Focus Theme 2 – 20/2000
- European Handbook for Integrated Environmental and Economic Accounting for Forests – IEEAF (2000)
- Pilot Studies on NAMEAs for air emissions with a comparison at European level (1999)
- The Environmental Goods & Services Industry – Manual for data collection and analysis (OECD/Eurostat 1999)
- The European Framework for Integrated Environmental and Economic Accounting for Forests: Results of pilot applications (1999)
- From research to implementation: policy–driven methods for evaluating macro-economic environmental performance – proceedings from a workshop, Luxembourg 28-29 September 1998 (DG Research Report 1999/1)
- The European System for the Collection of Economic Information on the Environment – SERIEE 1994 Version (1994). Also available in DE, FR and ES.

Eurostat Working Papers *(available at http://forum.europa.eu.int/Public/irc/dsis/pnb/library)*

- Including chemical products in environmental accounts (2/2001/B/7)
- Water satellite accounts for Spain 1997-1999 (2/2001/B/6)
- Methods for estimating air emissions from the production of goods imported into the UK (2/2001/B/5)
- Towards a Typology of ‘Environmentally Adjusted’ National Sustainability Indicators (2/2001/B/4)
- Valuation of oil and gas reserves in the Netherlands (2/2001/B/3)
- Material use indicators for the European Union, 1980-1997 (2/2001/B/2)
- Uses of Environmental Accounts in Sweden (2/2001/B/1)
- Environment taxes and subsidies in the Danish NAMEA (2/2000/B/12)
- Environment taxes and environmentally harmful subsidies in Sweden (2/2000/B/11)
- The environment industry in Sweden, 2000 (2/2000/B/10)
- Material flow analysis in the framework of environmental economic accounting in Germany (2/2000/B/9)
- A materiel flow account for Italy, 1988 (2/2000/B/8)
- Environment employment in France, methodology and results 1996-1998 (2/2000/B/7)
- Material flow accounts - material balance and indicators, Austria 1960-1997 (2/2000/B/6)
- The environment industry in Sweden, 1999 (2/2000/B/5)
- Environment industry and Employment in Portugal, 1997 (2/2000/B/4)
- Environment-related employment in Netherlands, 1997 (2/2000/B/3)
- Material flows accounts – DMI and DMC for Sweden, 1987-1997 (2/2000/B/2)
- Material flows accounts - TMR, DMI and material balances, Finland 1980-1997 (2/2000/B/1)
- A material flow account for sand and gravel in Sweden (2/1999/B/4)
- The Environment Industry in Sweden (2/1999/B/3)
- Industrial Metabolism (2/1999/B/2)
- The Policy Relevance of Material Flow Accounts (2/1999/B/1)
- The Economy, Energy and Air Emissions (2/1998/B/2)
- Physical Input-Output Tables for Germany, 1990 (2/1998/B/1)
- An Estimate of Eco-Industries in the European Union 1994 (2/1997/B/1)

Summary

There is a growing interest in European Environmental Economic Accounting in analytical applications of the accounting framework and of the data bases being set up. A major focus for the time being is on emission accounts. One possibility in this field is to analyse the observed changes in emissions within a certain period by means of a structural decomposition method. The present paper describes the theoretical background of this analytical tool and shows different methodological approaches before focusing on the method applied in German Environmental Economic Accounting. The approach chosen is based on a method applied by Statistics Netherlands but is extended to be applicable to more general cases. The main chapter of the conceptual part in this paper is the elaboration and description of this extension. Theoretical considerations are followed by empirical results in the second part of the paper.

Acknowledgements

The empirical work on decomposition analysis of changes in carbon dioxide emissions presented in this paper was done in the Environmental Economic Accounting (EEA) division of the German Federal Statistical Office. The results were presented at the annual EEA press conferences in 2000, 2001 and 2002, respectively. In 2002, when input-output analysis was included, the EEA team closely worked together with the input/output division of the National Accounts department.

The data of the factors considered in our decomposition analysis were mainly prepared by Carmen Busch and Klaus-Dieter Würtz; they also ran most of the programmes. A big part of conceptual and interpretation work was done by Angela Heinze and Helmut Mayer.

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February 2003

1 Introduction

In the view of many people, the task of statisticians consists in collecting and presenting data: they carry out surveys, calculate figures and produce tables. In reality, this is only the "descriptive" part of the statisticians' work. The first paragraph of the German Law on Statistics for Federal Purposes specifies the tasks of the German national statistics: these tasks consist in investigating, collecting, preparing, presenting and *analysing* data (Gesetz über die Statistik für Bundeszwecke, January 1999 edition). On the international level, Eurostat is heavily interested not only in presenting European-wide figures but also in giving at least some examples for analytical work performed on the data. This for instance particularly holds concerning the work in the field of Environmental Economic Accounting (EEA), especially on the so-called National Accounting Matrices including Environmental Accounts (NAMEA). In these accounts, environmental-related figures such as energy consumption or air emissions are broken down by economic branches. Analysis of these data includes the calculation of indirect emissions allocated to final users, the calculation of indirect emissions embedded in international trade and the performance of so-called structural decomposition analysis of changes (NAMEA Air Task Force, final report of the 20-21 February 2002 meeting). The latter are the subject of the present paper.

Trends of a certain variable - such as energy consumption or the emission of a specific pollutant - usually are determined by a whole set of different factors. Especially since the eighties, there is a growing interest to separate these factors by analytical means (Diekmann et al. p 82). The most common tool to do this is called decomposition analysis, which in fact is the name for a large number of slightly different methods (Diekmann et al. give an overview).

Among the European national statistical institutions the Netherlands are very advanced in their work on decomposing environmental-related figures. Already in 2000, Statistics Netherlands presented a final report to Eurostat and the Directorate General for the Environment on "Decomposing annual changes in pollution according to their causes: a NAMEA time series analysis" (de Haan 2000). Meanwhile a couple of European countries have included (or are beginning to include) decomposition analysis into the work programme of their EEA statisticians. During the NAMEA Air Task Force's meeting on February 2002, examples were presented by the Netherlands, the UK, Norway and Germany. A small chapter on decomposition analysis is also included in the new world-wide handbook on integrated Environmental and Economic Accounting (SEEA).

For the time being the work of the German EEA on decomposition analysis is restricted to the analysis of carbon dioxide changes. The method used in general follows the Dutch approach (de Haan 2000) but includes some extension of the methodology as well as of the factors taken into consideration. The present paper wants to give some insight into the German work of the last three years, showing both theoretical aspects and results. The paper is organised as follows:

The first part is the theory part: Chapter 2 gives a simple introductory example of what decomposition means and how decomposition analysis works. We will see that decomposition work on a certain variable mainly can be classified according to the factors regarded as "underlying causes" for the observed changes and according to the (mathematical) method used to perform the decomposition. Chapter 3 summarises in short some possibilities to approach the decomposition problem but focuses on the presentation of the method chosen by the Netherlands (de Haan 2000). In chapter 4 this approach which in the quoted paper is limited to the case of four underlying factors is generalised to any number of factors. Chapter 5 shortly presents an alternative approach that we call "hypothetical emissions" and which is rather similar to decomposition analysis. This is only done for the sake of completeness and will not be further illustrated by actual numerical examples in the second part of the paper.

The second part is the empirical part: In chapter 6 the "extended" Dutch approach is used to decompose the carbon dioxide emissions of industries, the housing-related emissions of private households and the transport-related emissions of households. Chapter 7 analyses the impact of changing the level of disaggregation by branches. In chapter 8 we apply to the same set of factors a "simple" method that the German EEA had previously performed in 2000. For the sake of comparability, calculations are performed with actual data instead of the data we used in 2000. In chapter 9 we present the results we get if the extended method is applied to a restricted list of "simple" factors. Chapter 10 presents the case where both method and factors considered are rather simple.

A final chapter draws some conclusions from the experience made so far.

Part I: Theoretical considerations

2 The principle of decomposition analysis: an introductory example

The starting point for any decomposition analysis is an equation where the variable of which the observed changes shall be analysed is written as the product of the factors considered as "underlying causes". This equation cannot be derived but must be given by the analyst. The choice of the factors depends both on the "conceptual model" ("Which factors can reasonably be considered to have an impact on the interesting variable?") and on data availability. And, of course, the factors must fit to each other in the sense that their product equals the variable to be analysed. In practice, this latter condition in many (not all) cases is achieved by choosing factors that are ratios where the denominator of one factor equals the numerator of the next one.

As a very simple example, we can imagine the total energy use of production E written as the product of energy efficiency - that is energy used per unit of produced output: E/P - and the number P of produced units:

$$E = E/P * P$$

Where we want to end up is another equation where the observed *change* in E - denoted by ΔE - is "explained" by the corresponding changes in E/P and P respectively:

$$\Delta E = c*\Delta E/P + d*\Delta P$$

with coefficients c and d to be computable based on the observable data on E/P and P. Once the coefficients c and d are determined, the expressions $c*\Delta E/P$ and $d*\Delta P$ show to which extent changes in efficiency E/P and changes in production volume P are "responsible" for the observed change in overall energy use or - in other words - to which extent changes in efficiency or volume have an impact or effect on the energy use. This is why $c*\Delta E/P$ and $d*\Delta P$ are called *effects* (of energy efficiency and production volume respectively).

The coefficients c and d can easily be determined by some simple mathematical manipulations, but already our simple example with only two factors shows that the solution is not unique. The energy change ΔE can be written as E(1) - E(0) where 1 and 0 denote the corresponding points in time between which the change is observed. Remembering our starting equation E = E/P * P the following holds:

$$\begin{aligned}
\Delta E &= E(1) - E(0)\\
&= E/P(1) * P(1) - E/P(0) * P(0)\\
&= E/P(1) * P(1) - E/P\,(1) * P(0) + E/P(1) * P(0) - E/P(0) * P(0)\\
&= E/P(1) * [\ P(1) - P(0)\ ] + P(0) * [\ E/P(1) - E/P(0)\ ]\\
&= E/P(1) * \Delta P + P(0) * \Delta E/P
\end{aligned}$$

By inserting the expression E/P (1) * P(0) in line 3 of the above calculations, we see (in the last line) that the coefficient c equals P(0) and d equals E/P(1). Note that as requested c and d are computable on the basis of data on P and E/P. But we could as well have inserted E/P (0) * P(1) which leads to

$$\begin{aligned}
\Delta E &= E(1) - E(0)\\
&= E/P(1) * P(1) - E/P(0) * P(0)\\
&= E/P(1) * P(1) - E/P\,(0) * P(1) + E/P(0) * P(1) - E/P(0) * P(0)\\
&= P(1) * [\ E/P(1) - E/P(0)\ ] + E/P(0) * [\ P(1) - P(0)\ ]\\
&= P(1) * \Delta E/P + E/P(0) * \Delta P
\end{aligned}$$

which means that in this case c equals P(1) and d equals E/P(0). So we found two different possible solutions to the decomposition problem. Both of them show that the coefficient of a specific effect consists of the "remaining" factor evaluated either for time 1 or time 0.

It is worth thinking about how the difference between the two solutions could be interpreted. In the first case, the efficiency effect is due to the change of efficiency ∆E/P with a production volume remaining unchanged as it was in the starting year (P(0)). The volume effect is caused by the development of the production volume ∆P while efficiency is assumed to have already changed before (E/P(1)). This means that there is a precise order in which the effects occur: First we look at the efficiency, afterwards we look at the production volume. In the second case, it is the other way round.

A conclusion from this example is that there is not only a choice to be made concerning the factors considered in the starting equation but also a choice on the specific methodology applied to the performance of the decomposition. This latter aspect will be further discussed in the following chapters.

3 Different decomposition approaches

The introductory example of chapter 2 illustrated just one methodological approach among a wide range of possible proceedings. An overview may be found in Diekmann et al. According to these explanations, the approaches might be classified as follows:

1. In our example, the decomposition only considers *"isolated" effects*: Changes in energy use are influenced by changes in efficiency (while production volume is assumed to be constant) on the one hand and by changes in production volume (while efficiency is assumed to be constant) on the other hand. There is no *"mixed effect"* caused by a simultaneous or "interacting" change of efficiency and volume. Or in mathematical terms: We do not consider an effect described by the expression $\Delta E/P * \Delta P$.

2. If we look at the points in time where the coefficients c and d of the two effects $c*\Delta E/P$ and $d*\Delta P$ are evaluated we notice that our example performs a "mixed evaluation": either c equals P(0) and d equals E/P(1), or the two points in time are exchanged: c equals P(1) and d equals E/P(0). There also exist decomposition approaches where all coefficients are evaluated at the initial point in time (that is 0) - this corresponds to the application of a *Laspeyres index* - or where all coefficients are evaluated at the actual point in time (that is 1) - this corresponds to a *Paasche index*. In both cases, the disadvantage of the approach consists in the occurrence of a "residual term" representing actually the mixed effects mentioned above. For example, the following mathematical equation holds:

   $$\begin{aligned}\Delta E &= E(1) - E(0)\\ &= E/P(1) * P(1) - E/P(0) * P(0)\\ &= \ldots\ldots\ldots\ldots\\ &= P(0) * [E/P(1) - E/P(0)] + E/P(0) * [P(1) - P(0)] + [E/P(1) - E/P(0)] * [P(1) - P(0)]\\ &= P(0) * \Delta E/P + E/P(0) * \Delta P + [\Delta E/P * \Delta P]\end{aligned}$$

   The first two items are very similar to what we had in our initial example except for the fact that the coefficients now are evaluated *both* at time t=0; but as a consequence, the equation contains the residual term $[\Delta E/P * \Delta P]$ which represents the simultaneous change of E/P and P and is indeed a mixed effect.

3. If an approach with a *residual term* is chosen, one has to decide how to apply it. In principle there are three main possibilities:
   - The residual term is so small that it can be neglected (which of course means that the decomposition is not exact but only a good approximation). This is often the case when only short periods are analysed and the factors are not subject to sudden changes.
   - The residual term is explicitly considered, which means that isolated and mixed effects are analysed.
   - The residual term is distributed among the different isolated effects.

4. For the analysis of longer time series one can decide whether to look exclusively at the *starting year and the actual year*, or whether to make a *year-by-year analysis* (and sum up the results).

5. One has to make a decision on the *level of disaggregation* of the sectoral breakdown. If the national economy is only represented by overall figures one will end up with a one-dimensional (scalar) equation. If a breakdown by industries is performed the factors become vectors (or even matrices) the dimension of which equals the number of different branches considered. Of course results will depend on the hierarchical level of this breakdown.

The approach of Statistics Netherlands (de Haan 2000) which is the guiding model for the German EEA work on decomposition analysis corresponds to our illustrative example. It is an approach *without* consideration of mixed effects, so there is *no residual term,* and the evaluation of the coefficients of the effects consists in a mixture of Laspeyres and Paasche approach (that means some factors are evaluated at the starting year and others at the actual year).[1] In spite of these decisions, the decomposition problem has no unique solution, as the example in chapter 2 shows. More generally, in the case of n factors there exist

$$n! = n * (n-1) * (n-2) * (n-3) * .... * 3 * 2 * 1$$

different decomposition forms (Dietzenbacher and Los 1998 quoted in de Haan 2000, p. 4). This can easily be understood if we remember that each decomposition form corresponds to a specific order in which the effects are addressed. For n factors there are indeed n! different possibilities to rank them.

To overcome this uniqueness problem, de Haan proposes to calculate the mean of all existing solutions. The reasoning is that, firstly, the average is the best estimate and that, secondly, the structure of the coefficients of the different factors is similar so that, as a consequence, a very effective algorithm can be established which avoids the explicit calculation of all existing n! decomposition forms (see de Haan 2000, pp. 6f.). Maybe we could add a third argument: As has been explained above, each decomposition form corresponds to a specific order (in time) of effects. In reality, such an order does not exist. So the calculation of the mean of all possible orders / decomposition forms seems to be an appropriate procedure. The algorithm is explained for the case of n=4 factors, but the paper gives no detailed information on how to proceed in the case of more (or less) than four factors.

The main argument is as follows (see de Haan 2000, pp. 6f.):

- The coefficient of each effect (which in turn corresponds to the change of one single factor) equals the product of all remaining factors (those which are assumed to be constant), each of them evaluated either for the initial or in the actual year. (In our illustrative example of chapter 2 with only two factors the coefficient for the efficiency effect was the production volume P(0) or P(1) and the coefficient for the volume effect was the efficiency E/P(1) or E/P(0)).
- With n factors under consideration, the number of the "remaining" factors is of course n-1, and with each of them being possibly evaluated in the initial and the actual year there are $2^{(n-1)}$ different possibilities for the coefficient of the effect in question.
- As n!, the number of different decomposition forms, is larger than $2^{(n-1)}$ for n > 2, at least some of the coefficients must appear in more than one of the n! decomposition forms.

De Haan describes the structure of the $2^{(n-1)}$ coefficients and indicates for each coefficient the number of appearances in the n! decomposition forms *for the case of n=4*, that means that 8 coefficients are given with their individual "weights". The case of more or less factors is left open. This will be the main subject of the following chapter of this paper.

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[1] The decision on one period analysis versus year-by-year analysis and the choice of the hierarchical level of the sectoral breakdown will be addressed in the empirical part of this paper.

4 Methodological extension of the Dutch approach

We now consider the universal case of n factors. The starting point of our work is the following information:

- There are n! different possible decomposition forms. Each of them corresponds to a certain order to address the factors and their effects.
- For every factor, there are only $2^{(n-1)}$ different possibilities to calculate the coefficient preceding the Δ-item of this factor (which means that some of the coefficients must appear several times).

The weight of a coefficient for a specific factor - that is the number of its appearances within the n! different decomposition forms - can be determined as follows:

1. Consider one specific factor. There are n different possibilities for this factor: It could have been addressed first, or second, or third, and so on until the possibility of having been addressed last (as number n). The probability of each of these n cases is exactly the same. As a consequence, with n! decomposition forms in total, there is an equal number of forms where the factor under consideration has been addressed first, second and so on. This number equals

   n!/n = (n-1)!

2. We already know that the coefficient of the factor in question (or its effect, respectively) is the product of the remaining (n-1) factors, each of them evaluated either at the initial or at the actual year. If the specific factor has been addressed first, all (n-1) remaining factors are evaluated at the initial year. If it has been addressed second, one of the remaining factors (the one that has been addressed first) is evaluated at the actual year, and (n-2) factors are evaluated at the starting year. If it has been addressed third, two factors are evaluated at t=1 and (n-3) at t=0. If it has been addressed last, all remaining (n-1) factors are evaluated at the actual year. The general rule is as follows: If the factor is addressed as number (k+1) - with k running from 0 to (n-1) - k of the remaining factors (those that have already been addressed before) are evaluated at t=1 and (n-1-k) of them are evaluated at t=0.

3. But which are the k factors from the total of (n-1) remaining factors? Statistical theory of combinations tells us that the number of possibilities to select k elements from a set of (n-1) equals

   (n-1)! / [(n-1-k)! * k!]

   In our special context, this is the number of possibilities to have a number of k factors evaluated at t=1 (and the rest at t=0) or, as a consequence, the number of different possible coefficients for the factor in question if it has been chosen as factor number (k+1).

4. Combining step 1 and step 3 gives us the following: Imagine our specific factor in question has been addressed as number (k+1). From step 1 we know that there are (n-1)! different decomposition forms (out of the total of n!) where this is the case. In any of them there must be a coefficient for the factor (or its effect, respectively). Step 3 tells us that there exist (n-1)! / [(n-1-k)! * k!] different coefficients for the case that the factor has been addressed as number (k+1). Dividing (n-1)! by (n-1)! / [(n-1-k)! * k!] gives us the weight we are looking for and which equals

   (n-1-k)! * k!

So in order to get the weight of a given coefficient, one has to count for the number k of factors that are evaluated for the actual year and then calculate (n-1-k)!*k!

We will illustrate the procedure for the case of five factors. With n=5 there are 5! = 120 different decomposition forms but only 2^4 = 16 different coefficients for each factor. (5-1)! / [(5-1-0)! * 0!] = 1 of them correspond to the case of k = 0, that is that the factor we consider has been addressed first (see step 3 above). This means that the remaining four factors are evaluated for t=0 (the initial year):

Remaining factor	**1**	**2**	**3**	**4**
Evaluated for time t=	0	0	0	0

The weight of this coefficient equals (5-1-0)!*0! = 24. This means that among the 120 decomposition forms there are already 24 where the coefficient of the effect under consideration looks as illustrated above.

A number of (5-1)! / [(5-1-1)! * 1!] = 4 coefficients correspond to the case of k = 1. They look like

Remaining factor	**1**	**2**	**3**	**4**
Evaluated for time t=	1	0	0	0
Evaluated for time t=	0	1	0	0
Evaluated for time t=	0	0	1	0
Evaluated for time t=	0	0	0	1

and have a weight of (5-1-1)!*1! = 6 each.

A number of (5-1)! / [(5-1-2)! * 2!] = 6 coefficients correspond to the case of k = 2. They look like

Remaining factor	**1**	**2**	**3**	**4**
Evaluated for time t=	1	1	0	0
Evaluated for time t=	1	0	1	0
Evaluated for time t=	1	0	0	1
Evaluated for time t=	0	1	1	0
Evaluated for time t=	0	1	0	1
Evaluated for time t=	0	0	1	1

all of them having a weight of (5-1-2)!*2! = 4.

The case of k = 3 is mirrored in the case of k = 1 (that means: one just has to exchange the indices 1 and 0); and in the same way k = 4 is equivalent to k = 0. We can check our calculations by summing up (for the cases k=0 to k = 4) the numbers of coefficients multiplied by their weights:

$$1*24 + 4 * 6 + 6 * 4 + 4 * 6 + 1 * 24 = 120$$

which is the total of different decomposition forms. The number of different coefficients equals

$$1 + 4 + 6 + 4 + 1 = 16$$

as stated above.

5 The concept of "hypothetical emissions"

When communicating such a decomposition approach to the public, it is important to give some simple interpretations of what the effects really mean. Very often, the arguing is as "An effect denotes what would have happened if only the factor under consideration had changed while all the others had not". This is rather easily to be understood, but in our case, where we have the "mixed evaluation", it is not quite correct: For those remaining factors which are evaluated at t=0 the interpretation holds, but for those evaluated at t=1 the assumption is that they already have changed. It is also possible to put it as follows: "An effect denotes what would have happened if only the factor under consideration had remained as before." In this case the interpretation is correct for all remaining factors evaluated at t=1 but does not hold for those evaluated at t=0. Indeed this mixture is *not* easily to be communicated.

This problem can be solved if all factors are evaluated at t=0 (which corresponds to the application of a Laspeyres index) or all factors are evaluated at t=1 (Paasche index; see chapter 3). The problem which arises is that the sum of the isolated effects does not equal the overall change of the analysed variable any longer: there is a residual term representing the mixed effects (see also chapter 3). If this residual term is neglected, the results do not fit to what people think a decomposition (in the strict sense of the word) should be (because there is a gap between the observed change in the variable and the sum of the effects which are shown, which indeed means that the change is not "really" or "fully" decomposed). For this reason German EEA preferred to avoid the expression "decomposition analysis" in this case (although formally it is a specific decomposition method as we have seen in chapter 3) and to speak of *"hypothetical emissions"*: the emissions we would have had if all but one factor did not change (or alternatively the emissions we would have had if only one factor did not change). The difference between the actual and the hypothetical emissions can be interpreted as effect. As well, one could speak of an "incomplete decomposition".

In summary, the choice between the methods is based upon the comparison of the advantage of an easier interpretation and the disadvantage of a gap between the observed change and the sum of effects (or, respectively, the advantage of a "full decomposition" and the disadvantage of a more complicated interpretation - at least if you want to be correct).

German EEA has tested the concept of hypothetical emissions in 2001 but decided to follow the full decomposition approach in the future. As a consequence, the empirical part of this paper will strictly focus on different results of this latter approach.

Part II: Empirical results

The German Environmental Economic Accounting division performed several different decomposition analyses of changes in carbon dioxide emissions in Germany. The analyses have in common

- that they cover the period from 1991 to 2000 or 1993 to 2000 respectively (in order to avoid special effects related to German re-unification),
- that in most cases, they are performed as a year-by-year decomposition (with summing up the results for the years to get the figures for the whole period) and
- that in general the national figures used are broken down by 70 homogenous economic branches according to the NACE classification.

As already mentioned in chapter 3 the approach is a combination of Laspeyres and Paasche index so that there are no residual term or mixed effects, respectively. The assumed independence of the effects must be kept in mind when interpreting the results.

The differences among the analyses concern the methodology applied in detail on one hand and the factors taken into consideration on the other hand. We use both a simple method and the extended method described in chapter 4, and we take into consideration both a simple set of factors and a larger set of more complicated factors (including input-output tables). The simple method means that we did not calculate the mean of all decomposition forms but only the two decomposition forms corresponding to the range of factors if one reads them from the left to the right and the order of factors if one addresses them from the right to the left. Methods and factor sets were cross-combined; the resulting four models are denoted as follows:

Model A: Extended method, factors including IOT
Model B: Simple method, factors including IOT
Model C: Extended method, simple factors
Model D: Simple method, simple factors

Details will be explained in the corresponding chapters.

The split by 70 branches means that the equations to be analysed are not one-dimensional but that we have to apply the rules of matrix-vector algebra. In particular it is important to take care whether to define a factor as a row vector or as a column vector; sometimes it might even be necessary to transform a vector into a diagonal matrix.

For the programme code, we used Visual Basic for Microsoft Excel.

Results of the German EEA decomposition analyses are also given in the reports of the EEA press conferences in 2000, 2001 and 2002 which are available as internet versions, too (see references).

6 Model A: "Extended method, factors including IOT"

We first describe the actual results that we get if we apply the method as laid out in chapter 4. The analysis was done separately for the carbon dioxide emissions of industries and those of private households (where, again, we separately looked at the emissions related to housing activities such as cooking or heating and those related to transport). The factors that are considered as underlying causes of the emission changes differ according to these three cases.

Industries

The factors for the industries include the use of input-output-tables (at constant prices of 1995; available at http://www.destatis.de/shop). The factors considered are as follows:

The first impact on the amount of carbon dioxide emissions is due to the content of carbon in the different kinds of energy used by the economic branches. There is a wide range from "clean" energy forms without any carbon (such as hydro or nuclear power) to energy containing much carbon (e.g. coal). The relative content of carbon is expressed by the ratio of carbon dioxide emissions (CO2) to energy input (E) and is called *emission intensity*. This emission intensity is influenced by the energy mix of production.

The second factor to be considered is the amount of energy needed to produce one unit of the good or service in question. The corresponding ratio of energy input E to production output O is called *energy intensity*. (Note that in this factor set the production volume is quantified by total output, not by gross value added.)

The remainder is the production volume O. This should be analysed in more detail because output depends both on intermediate and final consumption, the latter being interesting with regard to both structure and volume. As for the *final consumption volume* Ctot (where tot indicates that we sum up for all product groups) we took into consideration the total demand for *domestic and imported* goods and services. The *demand structure* vector is represented by the share of the final demand C for the *specific product group produced in the own country* on the overall demand volume Ctot (thus showing together the shares of the specific product groups restricted to domestic production and the share of imports which of course could be split up if desired).

In order to make the starting equation complete we still have to link the final demand vector C to the output vector O. This is done by applying the standard Leontief model: Consumption and output vector satisfy the equation

$$O = INV(I-A) * C$$

where INV(I-A) is the matrix resulting from inverting I-A with I denoting the unity matrix (with entries 1 on the diagonal and 0 elsewhere) and A the matrix of input coefficients resulting from the division of the entries of the symmetric input-output table (IOT) by the sum of the corresponding IOT-column. This Leontief matrix INV(I-A) represents the *structure of intermediate consumption* (of an infinite chain of production steps). Changes in this structure are mainly due to changes in production techniques - for example by substituting production inputs.

As we wanted to decompose "real" emissions, figures are not corrected for temperature effects.

With the factors introduced above, the starting equation for the decomposition analysis looks as follows:

$$CO2 = CO2/E * E/O * INV(I-A) * C/Ctot * Ctot.$$

As already mentioned in chapter 2 in many cases the factors are ratios where the denominator of one factor equals the numerator of the next one so that fractions can be reduced to make the equation hold.

The number of different decomposition forms in this case of five factors is 120; the structure of the coefficients for the five effects and their weights are as shown in the example of chapter 4.

The results are given in table 1. The analysis is restricted to the period from 1993 to 2000 in order not to be influenced by special effects related to German re-unification between 1991 and 1993.

In Germany carbon dioxide emissions of industries decreased from 691.142 million tonnes in 1993 to 660.566 million tonnes in 2000. This decline by 30.576 million tonnes is decomposed as shown in the column on the lower right hand side of table 1. Most of the reduction is due to an improved energy intensity which has an effect of about 62 million tonnes. This has been achieved to a large extent by the branches with the highest emissions shares (electricity supply and manufacture of metal products) which could offset the unfavourable development of other branches. In addition, one can assume that there is a considerable influence of temperature that was lower in 1993 than in 2000. A better emission intensity (mainly by manufacture of chemical products which reduced its use of coal) led to a reduction of about 27 million tonnes. Furthermore structural effects contributed to the decline in emissions. Changes in intermediate consumption structure caused the emissions to decrease by 37.8 million tonnes. This effect can be explained by an increase in the share of imported intermediate goods. Final demand structure caused an emission decline of almost 50 million tonnes. Once again, one driving factor is a shift towards imported goods, but in addition, there is a favourable trend concerning domestic products because demand for electricity and construction (both of them being rather emission-intensive) went down while demand for services went up.

Table 1: Decomposition of production-related carbon dioxide emissions in Germany 1993-2000 (extended method, factors including IOT) (1000 tonnes)

Effect of	**1993-1994**	**1994-1995**	**1995-1996**	**1996-1997**
Final demand volume	21 702	17 172	9 602	19 739
Final demand structure	-720	85	8 174	-7 741
Intermediate consumption structure	-9 981	4 136	81	-18 300
Energy intensity	-8 569	-29 093	-2 934	2 382
Emission intensity	-7 417	9 408	-9 175	-22 305
Sum = emission change	**-4 985**	**1 708**	**5 748**	**-26 225**

Effect of	**1997-1998**	**1998-1999**	**1999-2000**	**Sum 1993-2000**
Final demand volume	23 946	21 809	32 444	**146 413**
Final demand structure	-11 349	-22 954	-15 352	**-49 856**
Intermediate consumption structure	-5 734	-2 524	-5 508	**-37 830**
Energy intensity	-8 980	-16 670	1 834	**-62 029**
Emission intensity	1 649	4 874	-4 307	**-27 273**
Sum = emission change	**-467**	**-15 465**	**9 111**	**-30 576**

This means that the two intensity effects on the one hand and the two structural effects on the other have about the same magnitude, and all of them are favourable to emission decline. If there had not been a volume effect, emissions would have been reduced by about 177 million tonnes. An increase of final demand volume, however, had an enormous unfavourable effect of emission rise by 146.4 million tonnes. The biggest contributions were made by the final demand categories of exports and private consumption.

When looking in short at the yearly results the following observations can be made: The effect of final demand volume is unfavourable throughout the whole period with a tendency of even getting worse. For both structural effects of intermediate and final consumption after a short period from 1994 to 1996 when they had a positive sign (meaning that both factors caused an increase of emissions), they are favourable to emission reduction without interruption since 1996. Emission intensity and energy intensity are subject to more frequent changes concerning their impact on emission trend. The frequent changes in the direction of the emission intensity effect are mainly due to the respective trend of the share of emission-relevant energy use in total energy use.

Private households: housing

For the housing-related carbon dioxide emissions of private households the following factors have been considered:

Emission intensity is defined the same as for the production by the ratio of emissions (CO2) and energy consumption E, but only energy for "housing" purposes (above all: heating, preparing of hot water) is accounted for. *Energy intensity* is this amount of energy divided by the area A of living space. As figures are not corrected for temperature effects, annual changes in mean temperature will have a heavy impact on the energy intensity effect. Living space is written as the product of individual space (area per person: A/P), household size (number of persons per household: P/H) and number of households (H). From this results the following equation:

$$CO2 = CO2/E * E/A * A/P * P/H * H$$

The outcome of the decomposition analysis (for the full period from 1991 to 2000) is shown in table 2.

Table 2: Decomposition of housing-related carbon dioxide emissions of private households in Germany 1991-2000 (extended method, factors including IOT) (1000 tonnes)

Effect of	**1991-1992**	**1992-1993**	**1993-1994**	**1994-1995**	**1995-1996**
Household number	1 589	1 893	1 671	848	1 252
Household size	-613	-777	-1 238	-529	-884
Individual living space	588	712	2 826	1 947	1 816
Energy intensity	-5 646	7 367	-6 367	2 576	9 284
Emission intensity	-3 919	1 804	-2 893	-3 941	1 832
Sum = emission change	**-8 000**	**11 000**	**-6 000**	**900**	**13 300**

Effect of	**1996-1997**	**1997-1998**	**1998-1999**	**1999-2000**	**Sum 1991-2000**
Household number	660	270	878	1 017	10 078
Household size	-299	-444	-730	-784	-6 298
Individual living space	2 003	2 227	1 742	1 365	15 225
Energy intensity	-4 165	-5 638	-8 530	-5 504	-16 622
Emission intensity	-2 199	-3 014	-4 860	-1 994	-19 184
Sum = emission change	**-4 000**	**-6 600**	**-11 500**	**-5 900**	**-16 800**

Contrary to the analysis of the production-related emissions the qualitative character of the housing-related results could already be foreseen and were confirmed by the decomposition analysis. As there was a shift in energy mix for heating from coal towards gas (especially in the New Länder), emission intensity improved inducing an effect of 19.2 million t of emission decline. An effect of 16.6 million tonnes in the same direction is due to the improvement of energy intensity which in turn is mainly explained by temperature changes and additionally supported by means of heat insulation and energy saving behaviour of private households. On the other hand, living space went up with an overall effect of 19.0 million tonnes of emission increase. This latter increase is the result of several opposite trends: more individual space per person (effect: + 15.2 million tonnes), smaller household sizes (effect: -6.3 million tonnes) and an increasing number of households (effect: + 10.1 million tonnes). Summing up the effects, housing-related carbon dioxide emissions of private households declined by about 17 million tonnes from 131 million in 1991 to 114 million in 2000. The yearly results show that favourable effects concerning both emission intensity and energy intensity can constantly be observed since 1996. The signs of the living space effect and its three components did not change throughout the whole period.

Private households: transport

As for transport activities of private households, carbon dioxide emissions result from the burning of fuels by private-owned vehicles. Again, the relevant influencing factors are *emission intensity* (that is: emission per unit of fuel used), *energy intensity* (fuel used per km traffic performance), and the transport volume (quantified by the km of traffic performance), where the latter is broken down into *individual mobility* (km per person) and *household size* and *household number,* leading in the end to

$$CO2 = CO2/E * E/km * km/P * P/H * H.$$

Table 3 gives the corresponding figures of the decomposition analysis (period 1991-2000).

Table 3: Decomposition of transport-related carbon dioxide emissions of private households in Germany 1991-2000 (extended method, factors including IOT) (1000 tonnes)

Effect of	**1991-1992**	**1992-1993**	**1993-1994**	**1994-1995**	**1995-1996**
Household number	1 159	1 362	1 159	580	805
Household size	-447	-559	-858	-362	-568
Individual mobility	10 617	426	-2 171	1 276	1 106
Energy intensity	-10 071	-151	-2 073	95	-1 514
Emission intensity	-1 573	-767	421	-4 064	1 098
Sum = emission change	**-315**	**311**	**-3 522**	**-2 476**	**972**

Effect of	**1996-1997**	**1997-1998**	**1998-1999**	**1999-2000**	**Sum 1991-2000**
Household number	412	175	613	745	7 010
Household size	-186	-288	-509	-574	-4 353
Individual mobility	943	528	933	-3 482	10 175
Energy intensity	-1 152	268	-226	-376	-15 201
Emission intensity	-349	-246	-415	-542	-6 436
Sum = emission change	**-333**	**437**	**395**	**-4 230**	**-8 805**

Again the results of the decomposition analysis are not really surprising: emission intensity improved due to an increasing share of diesel oil; the corresponding effect is an emission decline of 6.4 million tonnes. The development of fuel saving engines reduced energy intensity with a resulting effect of - 15.2 million tonnes. And again the volume effect is unfavourable (+ 12.8 million tonnes) mainly caused by the increase of individual mobility (effect: + 10.2 million tonnes) and the increasing number of households (effect: 7.0 million tonnes), only partly offset by the effect of smaller household sizes (- 4.4 million tonnes). Total transport-related carbon dioxide emissions of private households declined by 8.8 million tonnes from 93 million in 1991 to 84 million in 2000. Most recently (1999 to 2000) individual mobility trend has a favourable impact on emissions, too.

It has already been mentioned that the choice of relevant factors is up to the analyst. In the analysis above, for example, it may be considered to add disposable income as one of the explanatory factors (assuming that rising income would lead to higher emissions).

It may also be noted that a decomposition of the population into the two factors household size and number of households is meaningful only if each component is likely to have an independent effect. For example, it may be assumed that if a given population is distributed over a larger number of households (i.e., the household size declines), then the need for individual mobility may well rise.

In general, the choice of the factors is a crucial element of the analysis. The results will be as meaningful as this initial choice. As an extreme example, if in the analysis above one used the factor ‘number of households with internet access’ it might well be found that this factor has an effect. The choice of the factors should therefore be based on established theories.

7 The impact of the disaggregation level

The results for the carbon dioxide emissions of industries presented in the first part of chapter 6 have been obtained by using a disaggregation by 70 branches. If a different level of disaggregation is chosen, the resulting effects will be different. Especially, there will be a shift from the intensity-related effects toward the structure-related effects or vice-versa.

This can easily be understood by a simple heuristic example: Imagine you are looking at the national economy as a whole (that is you have no breakdown by industries at all). Suppose you can observe a decline in emissions which - if production volume is assumed to be constant - is due to an amelioration of emission (or energy) intensity. Now imagine you break down the economy by just two branches, one of them producing goods which are rather energy-intensive and the other one having a production that only needs a small amount of energy. If the relative shares of these two branches on total economic growth (which again we assume to be constant) is shifting there are two possible cases: If the less energy-intensive branch is growing (and the energy-intensive one is going down) part of the observed emission reduction (which had been attributed totally to the intensity effect when looking at the whole economy) in reality is caused by a structural change. This means that the intensity effect will be less than in the case of no breakdown, and there will be a structural effect in addition. But on the other hand, if the energy-intensive branch is growing (which of course means that there will be a structural effect having the opposite sign) the intensity effect must be even bigger than what had been calculated before for the whole economy because in addition to its previous amount it has to offset the negative structural impacts.

The example illustrates that as effects can have both a positive or a negative sign it is not possible to predict the "direction" of change when turning from one of disaggregation level to another.

In order to get an idea of magnitudes, German EEA in addition to the calculations of chapter 6 has performed the same decomposition of production-related emission changes for the cases of a disaggregation by 58 and by 12 industries. The results are shown in tables 4 and 5 respectively.

Table 4: Decomposition of production-related carbon dioxide emissions in Germany 1993-2000 (58 branches) (1000 tonnes)

Effect of	**1993-2000**
Final demand volume	146 414
Final demand structure	-42 052
Intermediate consumption structure	-55 075
Energy intensity	-51 843
Emission intensity	-28 020
Sum = emission change	**-30 576**

Table 5: Decomposition of production-related carbon dioxide emissions in Germany 1993-2000 (12 branches) (1000 tonnes)

Effect of	**1993-2000**
Final demand volume	146 387
Final demand structure	-43 478
Intermediate consumption structure	-81 124
Energy intensity	-33 197
Emission intensity	-19 164
Sum = emission change	**-30 576**

We see that indeed the emission decline of 30.6 million tonnes is decomposed into the five effects in a different way according to the disaggregation level of branches breakdown. Of course the final demand volume effect remains virtually unchanged because the corresponding factor is a scalar. The final demand structure effect does not change dramatically. It is an example of the above mentioned case that both directions of change are possible: When turning from the 70 to the 58 industries disaggregation level the amount of the demand structure effect goes down, but when further aggregating to a 12 industries level it slightly rises again (please compare tables 3, 4 and 5). The intermediate consumption effect clearly increases if branches are aggregated together. On the contrary, the energy intensity effect apparently goes down. The emission intensity effect shows a behaviour similar to the final demand structure effect as its direction of change is not identically oriented throughout the aggregation procedure.

If the two structural effects are added and the two intensity effects are added as well, the approximate equilibrium at the 70 industries level (structure effects: - 87.7 million tonnes, intensity effects: - 89.3 million tonnes) changes with the aggregation of branches towards a growing importance of structural effects and a declining impact of intensity aspects.

In this context it is worth stressing the fact that all analyses we describe in this paper are analyses of nation-wide emission changes. When talking about disaggregation level of branches we mean that we look at the impact that the breakdown we apply for our calculations has on the decomposition results for the whole economy. Of course it is possible to separate the different branches in the results. In terms of mathematics one just has to look at the different components of the emission change vector separately instead of summing them up. An example for such a presentation is the table below which shows the results of decomposition analyses for CO2 emissions for the Netherlands and the United Kingdom.

We want to put emphasis on the fact that interpretation might be not as simple as that: The Leontief matrix links every branch to all the others. As a consequence, reading the decomposition results "component-wise" implies that we explain the emission change of a specific branch not only by factors influenced by this sector exclusively (such as energy intensity for example) but also by factors involving all the remaining branches (such as the intermediate consumption structure matrix or the factor of *overall* final demand volume).

Decomposition of the change in CO_2 emissions by industries in the Netherlands and the United Kingdom (% of the total change relative to the base years)

	The Netherlands, 1987-1999				**The United Kingdom, 1990-1998**			
	Efficiency change	Structural change	Economic growth	**Total change**	Efficiency change	Structural change	Economic growth	**Total change**
Agriculture, forestry, fisheries	**-0.2**	**-1.8**	**3.0**	**1.0**	**0.1**	**-0.2**	**0.2**	**0.1**
Crude petroleum and natural gas production	*0.6*	*-0.2*	*0.4*	***0.8***	*-1.1*	*1.3*	*0.8*	***0.9***
Manufacture of petroleum products	*-0.5*	*-1.0*	*2.5*	***1.0***	*-0.4*	*-0.1*	*0.8*	***0.3***
Manufacture of chemical products	*-5.1*	*0.3*	*5.0*	***0.2***	*0.0*	*-0.3*	*0.5*	***0.3***
Manufacture of basic metals	*-0.5*	*-0.2*	*1.7*	***0.9***	*0.2*	*-1.3*	*1.0*	***-0.1***
Other mining and manufacturing	*-1.3*	*-0.6*	*3.0*	*1.1*	*-1.0*	*-2.5*	*1.8*	*-1.7*
Mining and manufacturing	**-6.8**	**-1.7**	**12.6**	**4.1**	**-2.3**	**-3.0**	**5.0**	**-0.3**
Electricity, gas and water supply	**1.2**	**-4.4**	**9.7**	**6.5**	**-14.7**	**-0.8**	**5.3**	**-10.2**
Land transport	*-0.8*	*0.5*	*1.7*	***1.4***	*-0.8*	*0.2*	*0.9*	***0.3***
Water transport	*-0.2*	*0.3*	*1.4*	***1.5***	*0.1*	*0.1*	*0.4*	***0.5***
Air transport	*-3.1*	*3.3*	*2.0*	***2.2***	*-1.0*	*2.4*	*0.8*	***2.2***
Sewage and refuse disposal	*0.7*	*0.9*	*0.8*	***2.4***	*-0.2*	*0.1*	*0.0*	***-0.1***
Other services and construction	*-2.9*	*0.0*	*3.9*	*1.0*	*-1.9*	*0.2*	*1.8*	*0.1*
Total services and construction	**-6.3**	**5.1**	**9.8**	**8.6**	**-3.8**	**2.9**	**3.9**	**3.1**
Total change in CO_2 emissions	**-12.1**	**-2.9**	**35.1**	**20.2**	**-20.7**	**-1.1**	**14.4**	**-7.4**

Source: Handbook of Integrated Environmental and Economic Accounting (SEEA 2003, forthcoming).

The table shows that the factors driving emissions changes can differ substantially across countries. For example, the reduction in the emissions from the UK electricity, gas and water supply industry are mainly due to fuel switching (increased use of natural gas) whereas the Dutch electricity industry used mainly natural gas throughout the period covered. The increase in emissions of the Dutch sewage and refuse disposal industry is mainly due to increased incineration of waste.

The table also illustrates that in both economies the structural change component makes a relatively small net contribution to emission reduction at the aggregate level. However, this masks the impact of more substantial structural change within certain sectors such as agriculture, mining, manufacturing and electricity supply which is largely cancelled out by structural changes within the services sectors, in particular the increased residual emissions from transport services.

8 Model B: "Simple method, factors including IOT"

For the case of emissions being caused by production activities the method and factors applied in chapters 6 and 7 shall be compared to what we get when using a more simple method and/or a more simple set of factors. These analyses are restricted to the period of 1993 to 2000, and we only have a look at the summed-up figures for the whole period. Calculations are performed at the disaggregation level of 70 industries.

If we take into consideration the same factors as above but do not calculate the mean of all possible decomposition forms, results will depend on the specific form we calculate (or, as has been explained in chapter 3, on the specific order in which we address the factors). If the factors of the equation

$$CO2 = CO2/E * E/O * INV(I-A) * C/Ctot * Ctot.$$

are addressed from the left to the right (that means if emission intensity is changing first and final demand volume at last) the figures presented in table 6 will result; if we do it the other way round (demand volume is changing first and emission intensity at last) we get the figures of table 7.

Table 6: Decomposition of production-related carbon dioxide emissions in Germany 1993-2000 (simple method, factors including IOT addressed from bottom to top) (1000 tonnes)

Effect of	**1993-2000**
Final demand volume	143 438
Final demand structure	-49 957
Intermediate consumption structure	-38 332
Energy intensity of output	-59 990
Emission intensity	-25 734
Sum = emission change	**-30 576**

Table 7: Decomposition of production-related carbon dioxide emissions in Germany 1993-2000 (simple method, factors including IOT addressed from top to bottom) (1000 tonnes)

Effect of	**1993-2000**
Final demand volume	149 310
Final demand structure	-49 717
Intermediate consumption structure	-37 208
Energy intensity	-64 215
Emission intensity	-28 746
Sum = emission change	**-30 576**

As can be seen, the amount of each effect is changing, but the overall magnitudes remain about the same as before. When comparing the above example to the average calculation (see table 1) one might get the impression that if the factor under consideration is addressed at an early stage its value goes up and if addressed at the end its value goes down. It is worth noting that it appears that in fact the values (and not the amounts) are affected in the described way: If addressed first (table 7) the demand volume effect reaches 149.3 million tonnes (which is more than 146.4 in table 1) whereas if addressed last (table 6) it only accounts for 143.4 million tonnes (which is less than in table 1). In the first case, emission intensity is addressed last inducing an impact of - 28.7 million tonnes (which is a value but not an amount less than -

27.3 in table 1), and in the second case, emission intensity is addressed first which makes rise the effect up to - 25.7 million tonnes (and again the value went up while its amount was going down). In other words: factors addressed at an early stage become more positive, that is positive amounts increase and negative amounts decrease (become less negative).

However, we can easily explain that this is **not** a general rule. Whether an effect will go up or down if the corresponding factor is addressed first will depend on the behaviour of the remaining factors. This can be understood if we remember that considering a specific factor at first means that the remaining factors are evaluated for the initial point in time t=0. On the contrary, addressing the specific factor at last means the remaining ones are evaluated for the actual time t=1. So it will obviously depend on these values (that is whether between t=0 and t=1 the other factors will rise or decline) whether the effect of the specific factor will go up or down.

9 Model C: "Extended method, simple factors"

While the choice of applying the extended or the simple method is a matter of a more complicated or a more straightforward programme code, the selection of factors in practice is determined mostly by data availability. Among the factors presented in chapter 6 the Leontief matrix which is based on the input-output table might cause the biggest problem, because in most cases annual input-output tables are not available. When beginning to work in the field of decomposition analysis, German EEA had this problem, too. The solution was to start with a restricted set of simpler factors for which data already existed and to construct, with the help of these factors, an alternative initial equation for the decomposition analysis.

When input-output data are not available, the relation between produced output and final consumption cannot be modelled. This is why another way must be found to represent the volume effect. Instead of looking at the changes in final demand volume, the growth of the *gross domestic product* is taken as a direct measure for economic growth, and the vector of the *shares of value added* VA (by the different branches) in the national GDP serves as a proxy for the economic structure (which was represented both by the Leontief matrix and the vector of shares of final demand before). As a consequence, in order to get a correct initial equation for the analysis, *energy intensity* cannot be referred to total output any longer but must be referred to value added. *Emission intensity,* on the contrary, can be defined as before.

The starting equation for the analysis which now consists of one factor less looks as follows:

$$CO2 = CO2/E * E/VA * VA/GDP * GDP$$

Performing the decomposition analysis (with the extended method) gives the results as presented in table 8. The calculation in this case had not been performed as a year-by-year analysis but as a calculation for the entire period.

Table 8: Decomposition of production-related carbon dioxide emissions in Germany 1993-2000 (extended method, simple factors) (1000 tonnes)

Effect of	**1993-2000**
Volume resp. growth (GDP)	93 565
Structure (GVA/GDP)	78 186
Energy intensity	-174 761
Emission intensity	-27 565
Sum = emission change	**-30 576**

Apparently, the effects heavily depend on the definitions of the factors. The emission intensity which is the only factor where the definition remained unchanged induces an effect that consequently is about the same as before (- 27.6 million tonnes compared to - 27.3 million tonnes in table 1). But the energy intensity effect rises up to - 174.8 million tonnes which is an increase by a factor of 2.8. The structural effect even changes its sign: While before the sum of intermediate and final demand structure effect was - 87.7 million tonnes (table 1) there is now an opposite effect of + 78.2 million tonnes. The growth effect keeps its positive sign (which means that it is unfavourable) but only has an amount of 93.6 million tonnes (compared to 146.4 million tonnes with the previous list of factors in table 1).

In our opinion the main reason for the differences is that with the factors as defined in this chapter imported intermediate goods and services and final demand for imports are completely neglected: As there is a growing share of final demand for imported goods, it seems logical that "growth" is faster when described by overall final demand (for domestic *plus imported* goods) than in the case where it is described by GDP, thus inducing a larger (unfavourable) volume effect in table 1 than in table 8 in the present chapter. Remember the fact that overall final demand includes all final demand categories (in particular it includes exports).

As a consequence of this higher growth effect, because all effects must sum up to the total emission decline and the emission intensity effect remained unchanged, the remaining two effects (energy intensity, structure) would be expected to be smaller than (or even opposite to) their counterparts in chapter 6. The structural effects of chapter 6 include a big part of this above mentioned growing share of final demand for imports (which of course reduces domestic emissions, see the final demand structure effect), and in addition for intermediate consumption there is a shift towards imports, too, which also contributes to the results of chapter 6 (see intermediate consumption structure effect). Amelioration of production techniques cannot be taken into account either (it has an impact on the Leontief matrix but not necessarily on the share of GDP). Without these influences it appears that economic structure changes even have an unfavourable impact on the emission trend.

We want to stress the fact that an increase in external trade relations is affecting different factors according to their definition: Growing exports will raise the volume effect. Growing imports on the other hand have a wide range of possible impacts depending on the factors' definitions: In the case of the factors of chapter 6, growing imports (for both intermediate and final consumption) further increase the volume effect (remember: volume Ctot was defined as final demand for domestic *and imported* goods). If final demand for import is even growing faster than final demand for domestic products (which was the case in Germany) it leads to a decrease of the final demand structure effect at the same time (where decrease of course means in this case that the effect is environmentally favourable). In addition, the intermediate demand structure effect is affected in a favourable way (because of the shift from domestic to foreign intermediate goods and services). On the contrary, with structure defined as share of GDP as it is done in the present chapter, all these influences do not matter.

As for energy intensity, at first sight it seems difficult to give a striking interpretation of this remarkable increase compared to chapter 6. Maybe the simplest understanding is that, if all other effects are explained, the energy intensity effect is the "residual" to end up with the total emission change. And indeed, one can give an explanation by arguing as follows: Imagine production techniques are getting better not only in terms of a decreasing energy use (this of course is described by the energy intensity effect, no matter whether energy is related to output or to gross value added), but also in terms of a decreasing need for material input (which means: less intermediate consumption). With the factors of chapter 6, the consequences of this amelioration are shown within the structure effect (intermediate consumption structure) because the coefficients of the Leontief matrix are affected. Now remember that intermediate consumption plus gross value added equals output. With output growing in tendency, and the share of intermediate consumption going down due to the assumed amelioration of production techniques, this means, as a consequence, that gross value added is growing faster than output. This in turn implies that energy intensity improves more if energy (the numerator of the ratio) is related to the denominator gross value added than if it is related to output. This explains why the energy intensity effect is "better" with the simple set of factors.

10 Model D: "Simple method, simple factors"

At last we have a look at the case where the simple factors introduced in chapter 9 above are combined with the simplified method as already applied in chapter 8, where only two specific decomposition forms are calculated instead of the average of all possible forms. The figures are shown in table 9 (for the decomposition form where emission intensity is changing first and the factors are addressed from the bottom to the top) and table 10 (for the decomposition form where GDP is changing first and the factors are addressed from the top to the bottom), respectively. Again there was no year-by-year analysis.

Table 9: Decomposition of production-related carbon dioxide emissions in Germany 1993-2000 (simple method, simple factors addressed from bottom to top) (1000 tonnes)

Effect of	**1993-2000**
Volume resp. growth (GDP)	84 099
Structure (GVA/GDP)	47 572
Energy intensity	-136 313
Emission intensity	-25 933
Sum = emission change	**-30 576**

These tables do not really give new insights. Compared to table 8 (see chapter 9) the results in tables 9 and 10 behave as the results in tables 5 and 6 (see chapter 8) did in comparison to table 1.

Table 10: Decomposition of production-related carbon dioxide emissions in Germany 1993-2000 (simple method, simple factors addressed from top to bottom) (1000 tonnes)

Effect of	**1993-2000**
Volume resp. growth (GDP)	100 828
Structure (GVA/GDP)	114 787
Energy intensity	-217 779
Emission intensity	-28 412
Sum = emission change	**-30 576**

11 Conclusions

As has been demonstrated, decomposition analysis is a powerful tool to give some insight into the problem to which extent underlying causes contribute to the observed overall change of a given variable such as carbon dioxide emissions. It provides an answer to the question "Which part of the observed emission change is due to factor xy?". This part has been called effect. Remember that effects can have both a positive or a negative sign, so that they can offset each other.

When deciding on a concrete application of a decomposition one has to choose a specific methodology and a specific set of factors considered as underlying causes. These two choices are independent.

As for the methodology, there is a wide range of possible approaches. German EEA prefers a method with a "full" decomposition without residual term because it better fits to the idea of decomposing a total into its parts. Showing tables where the effects do not sum up for the total of emission changes provokes questions where the answer quickly leads to very technical discussions. One has to realise, however, that the interpretation of an effect as "What would have happened if all the other factors had remained unchanged" or the like in this case is correct only approximately because some of the remaining factors are assumed to be unchanged and the rest is assumed to have already changed before. Instead, one should speak of "the remaining factors being constant" which is correct (and more neutral). Of course, one renounces the possibility to communicate the straightforward interpretation "What would have happened if ...".

The next question is whether to apply the extended method where the average of all possible decomposition forms is calculated or whether to choose the simple method where only one decomposition form (corresponding to a certain order in which the factors are addressed) is necessary. Here we definitely prefer the first solution. De Haan (2000) shows that results may differ to a considerable extent when changing the order of factors. These differences are not easily communicated even to an interested public, and in addition, the choice of a specific order of factors also might cause some discussions. As a consequence, calculating the mean really seems to be the appropriate way. The disadvantage of a more complicated programme code is not a serious one at all, and we made the experience that runtime is nearly not affected.

As for the factors, of course they have to be chosen in a way to fulfil a correct starting equation: their product must equal the variable to be analysed (e.g. the carbon dioxide emissions). Which factors should be chosen is a question of both the aim of the analysis and data availability: The factors must be relevant (and it is up to the analyst to decide on this), and there must be the possibility to quantify them (with a reasonable input of work). In this sense the use of input-output tables might cause the biggest problems because their calculation is very time consuming. Therefore our suggestion is to start with the simple factor set and to try the complex one as soon as IOTs are available. (Remember that in the first case the factor energy efficiency is related to gross value added, whereas in the second case is it related to output.) When fitting the programme code to the factor set it is important to pay attention to a correct application of matrix-vector algebra.

Runtime is a bit higher in the case where the Leontief matrix is involved because the performance of a matrix-vector-multiplication requires more time.

German EEA will make decomposition analysis an instrument regularly applied for the analysis of carbon dioxide emission changes. In addition, it is planned to use it for the analysis of other variables. In 2003 tests are also foreseen on the changes in land use.

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