STATISTICAL COMMISSION and ECONOMIC COMMISSION FOR EUROPE

COMMISSION OF THE EUROPEAN COMMUNITIES

CONFERENCE OF EUROPEAN STATISTICIANS

EUROSTAT

Joint ECE/Eurostat Work Session on Methodological Issues of Environment Statistics
(Ottawa, Canada, 1-4 October 2001)

WORKING PAPER No. 2

ORIGINAL: ENGLISH

ECO-EFFICIENCY INDICATORS IN GERMAN ENVIRONMENTAL ECONOMIC ACCOUNTING

Paper submitted by the Federal Statistical Office of Germany[1]

Abstract: Any economic activity involves using the natural environment. At the same time the principle of sustainable development requires to deal with nature as carefully as possible. Therefore it is important to measure how and to which extent nature is used by economy over time. There are three essential classes of input factors from nature into economy that may be distinguished: the supply of goods (such as raw materials), the supply of area for the location of economic activity and nature's function as a sink for the discharge of residuals and pollutants. For these classes more detailed input factors can be specified. In addition to the measurement of mere quantities information on the efficiency of the factor use is of major importance. In German Environmental Economic Accounting (EEA) productivity indicators are used to measure eco-efficiency at the national level. The article describes how productivities are defined and which natural input factors are covered in German EEA. Two examples (raw materials, carbon dioxide emissions) show in detail how the productivities are calculated. The methods described are illustrated by various figures for Germany.

1 Productivity as a measure for eco-efficiency

Any economic activity, be it the production of goods and services, be it consumption, involves using our natural environment. There are many ways of using nature. Materials are withdrawn from nature as raw materials, areas are used as a location for economic activities, and for the discharge of residuals and pollutants nature is used as a sink, i.e. substances are taken up by nature.[2] By this the environment provides various inputs - in the form of (non produced) goods or services - to economy which are essential for the generation of economic output.

---

[1] Prepared by Dr. Hartmut Höh, Dr. Karl Schoer, Steffen Seibel

[2] In addition to its function as a sink, other services provided by nature should be mentioned such as the buffer, recreation and production functions.

Doing business in line with the principle of sustainable development requires dealing with nature as carefully as possible, that future generations may enjoy an intact environment, too. This means that the quantitative use of nature should be as small as possible or respect natural assimilation capacities. Looking at the quantities of natural input factors exclusively, however, would only give half of the picture: It is also important how much is produced by using one unit of nature as input. In the current debate those aspects are discussed under the priciple of eco-efficiency. Both aspects - sufficiency and efficiency - complete each other in showing how any economic activity deals with nature.

In this context, eco-efficiency indicators play the role to show how efficient the economic activity under consideration deals with nature's goods and services. This can be measured by establishing a mathematical relationship between economic output and environmental input. Most commonly the ratio of output and a special input is used. In general such an expression is called productivity. This term was originally used in a technical context, showing how much output can be generated from one unit of input by the production process being discussed. In economy the denominator of the ratio is often more restricted, especially to the economic input factors of labour and capital. It must be noted, however, that on the national level the reciprocal value, i.e. the ratio of input and output, called intensity, is also a common measure of efficiency which is often used in sectoral analysis or indicator systems.

Environmental Economic Accounting (EEA) is a framework which is designed to complete the national accounting by taking into consideration the relationships between economy and environment. Following the proposals of the SEEA (System of Integrated Environmental Economic Accounting) one major issue is the extension of the concept of produced assets as it is being applied in national accounts to a wider concept including non-produced natural assets. Consequently nature has to be considered a production factor. As such eco-efficiency indicators fit quite well to EEA concepts. It has to be realised, however, that consequently eco-efficiency indicators in the context of EEA are designed for the national (macro) level exclusively - the same way as it is done for the productivities of the economic input factors labour and capital. The parallel treatment of labour, capital and nature as production factors in EEA means that for indicating eco-efficiency productivities are better suited than intensities in the context of EEA.

The numerator of the productity expressions to be calculated is quantified according to the measurement of capital or labour productivity: The gross domestic product (at constant prices) is taken in order to represent the economic output (see table 1).

Table 1: Definition of productivity

Productivity – An indicator of the efficiency of factor use

The productivity of an input factor indicates how much economic output is produced by using one unit of the factor concerned.

$$\textbf{Productivity} = \frac{\textbf{Gross domestic product (at constant prices)}}{\textbf{Input factor}}$$

Productivity indicates how efficiently a national economy deals with the use of labour, capital and nature.

The calculation of the denominator, however, deserves some more attention. One has to decide

a) which specific environmental inputs have to be taken into account and
b) how the quantity of the specific input under consideration can be measured.

The physical supply of goods by nature comprises raw materials, water and energy. In addition, nature provides area which is used as location for economic activties. Nature's function as a sink can be considered as the input of various services. Here the reception of greenhouse gases, of acidification gases, of waste and of waste water are of major importance.

The supply of raw material, water, energy and area can easily be expressed in physical terms. On the contrary, the services corresponding to the use of nature as a sink for residuals and pollutants cannot be measured directly. Therefore the quantities of residuals and pollutants discharched from economy to nature are taken as best available approximations. This means that for example nature's input of the service "sink for greenhouse gases" is measured approximatively by the annual amount of greenhouse gas emissions. Table 1 summarizes which input factors of nature into the economy are considered in productivity calculations in German EEA and how they are measured.

Table 2: Input factors for productivity representation in German EEA

Input factors	
In German EEA productivities are presented for the use of the following input factors from nature:	
Nature as a source of resources	
Area	Area use as built-up land and land used for traffic purposes (mn km^2)
Energy	Energy consumption as the consumption of primary energy (petajoules)
Raw materials	Raw material consumption measured as the quantities of abiotic raw materials withdrawn from domestic nature and used plus imported abiotic goods (mn t)
Water	Water consumption as the quantity of water withdrawn from nature (mn m^3)
Nature as a sink for residuals and pollutants	
Greenhouse gases	Pressure on the environment through the emission of greenhouse gases (mn t CO_2-equivalents)
Acidification gases	Pressure on the environment through the emission of acidification gases (mn t acidification equivalents)
For comparison: The use of economic factors	
Labour	Volume of labour as the total of hours worked (mn hours)
Capital	Capital use as consumption of fixed capital (DM mn at 1995 prices)

Already here - before even having seen any figures - several crucial conclusions can be drawn:

- Eco-efficiency cannot be measured by one single number but consists of a vector of various productivities according to the different inputs from nature to economy.
- It must also be noted that for the calculation of each of these productivities the entire real yield of the economic activity is referred only to the production factor concerned, although the product is created through the combination of all production factors. Therefore these partial productivities as calculated can serve only for rough orientation.
- Due to their different qualities and functions, those factors (and the corresponding productivities respectively) cannot directly be compared with each other. However, by observing their development over long periods one may obtain information on how the relations between the factors have changed.

In the following, the calculation of two of the above mentioned input factors will be further explained (see section 2). The methods will be illustrated by showing figures for Germany. The examples of raw materials (section 2.1) and carbon dioxide emissions (section 2.2) cover the functions of nature as a provider of (physical) goods and as a sink for pollutants. In section 3, results for all input factors (and the corresponding productivities) will be given, and some main conclusions will be drawn.

2 The use of input factors

2.1 Withdrawal of raw materials

For the representation of material flows, the Federal Statistical Office has chosen a pragmatic approach – in particular because of data availability – which has included direct material flows but excluded indirect material flows for the time being. Direct use of material covers the withdrawal of raw materials, whether or not utilised, from domestic nature and the imported materials (raw materials as well as finished and semi-finished products). Indirect use of material covers the withdrawal of materials from nature in the rest of the world in the context of producing the goods later imported to Germany.

Representing indirect withdrawal of material appears necessary because the principle of sustainability in using nature applies not only at the national but also at the global level. Especially where domestic raw materials are substituted by foreign raw materials or by less material-intensive finished or semi-finished products (example: electricity imports instead of domestic coal extraction), the withdrawal of raw material in the rest of the world increases despite the decreasing use of material within the country.

Indirect use of material, however, is very difficult to determine with a satisfactory degree of accuracy. This is because it requires both data on the quantity of material not utilised in the context of extracting the imported raw materials abroad and information on the quantity of material used in producing the imported finished and semi-finished products. The Federal Statistical Office intends to improve the database for such calculations to the extent that it will be possible to perform such estimations with sufficient accuracy.

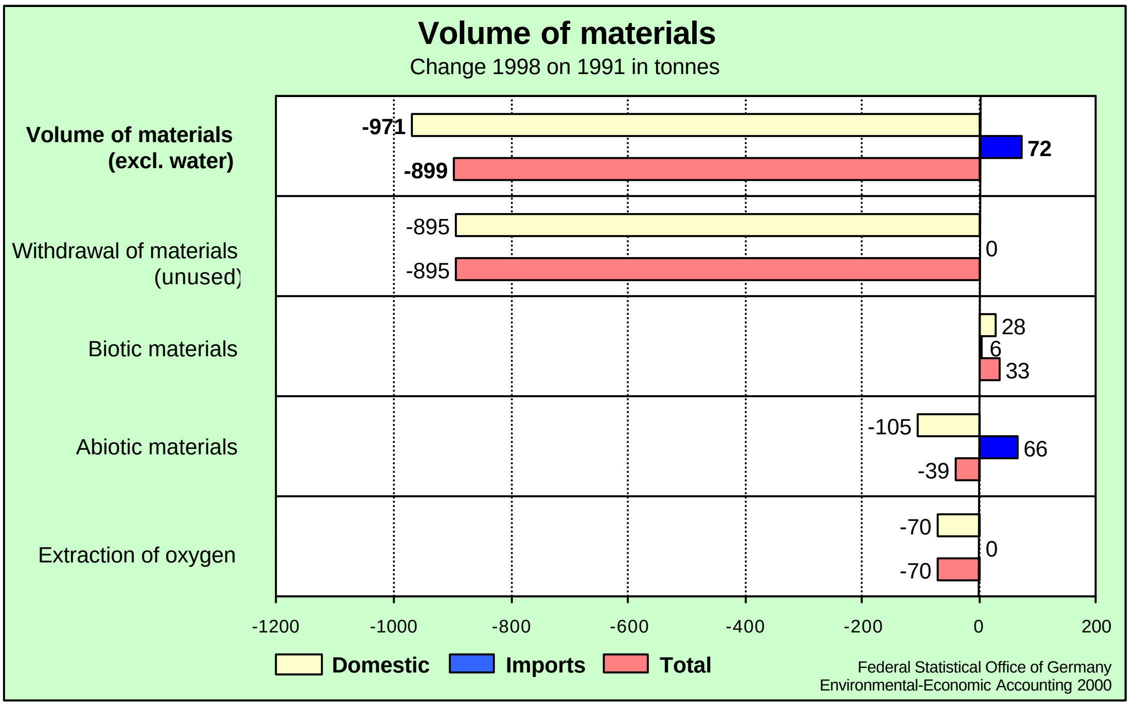
Direct use of material can be broken down into different material categories. This is important because only one of them is used to calculate the raw material productivity in Germany. For the withdrawal of raw materials from domestic nature - excluding water which is treated in a separate accounting module and including material imports from abroad - German EEA distinguishes

- unused materials (such as excavated waste material in mining, excavated earth and the like),
- biotic (renewable) materials (plants, animals),
- abiotic (non-renewable) materials (used) and
- the extraction of oxygen (mainly due to the burning of energy sources).

For each of these categories the material withdrawal is calculated at an aggregated level in physical units (tonnes). Only the withdrawal of abiotic material is used as the reference value to calculate the German raw material productivity.

Figure 1 shows the volume changes of materials withdrawn in Germany between 1991 and 1998.

Figure 1: Changes in direct use of material in Germany between 1991 and 1998



Comparing the material flows for 1991 and 1998 shows that the total material input of the German economy fell during the 1990s. The volume of material (withdrawal of raw materials from domestic nature, excluding water and including the materials imported from the rest of the world) fell by 971 mn t (- 19%) to 4,150 mn t. This means that 51 t of materials per inhabitant were withdrawn for economic purposes in 1998.

The decrease in withdrawal of materials is due to several causes. The decline in total use of materials in Germany between 1991 and 1998 is mainly the result of a marked reduction of excavated waste material in brown coal mining (reduced to about two thirds), which, in turn, was the consequence of a decrease in brown coal extraction in the new Länder (East Germany). Extracting one tonne of brown coal produces almost ten tonnes of excavated waste material. As a result of the strong decline in excavated brown coal waste material, the total volume of the withdrawal of unused materials fell by nearly one third (- 895 mn t).

The withdrawal of materials subsequently used did not change very much over the period examined. However, the share of renewable (biotic) raw materials (including the products made of them) increased, while the share of non-renewable (abiotic) raw materials and the products made of them declined. The use of biotic materials (plants, animals) rose by 33 mn t between 1991 and 1998. The quantity of abiotic materials used was down altogether by 39 mn t, with the withdrawal from domestic nature (especially energy sources as well as stones and earths) decreasing by 105 mn t and imports of abiotic materials increasing by 66 mn t. The extraction of oxygen, caused especially by the burning of energy sources, was down by 70 mn t.

2.2 Emissions of carbon dioxide

Emissions of carbon dioxide (CO_2) are mainly created by the burning of energy sources. Such emissions are a major cause of the "greenhouse effect". The calculations are based on the energy consumption relevant for emissions, which covers only those energy sources whose consumption directly causes emissions into the air. The corresponding emissions are called "direct emissions". Total energy consumption, however, covers also those energy sources whose consumption does not directly cause emissions (especially electricity and remote heating).

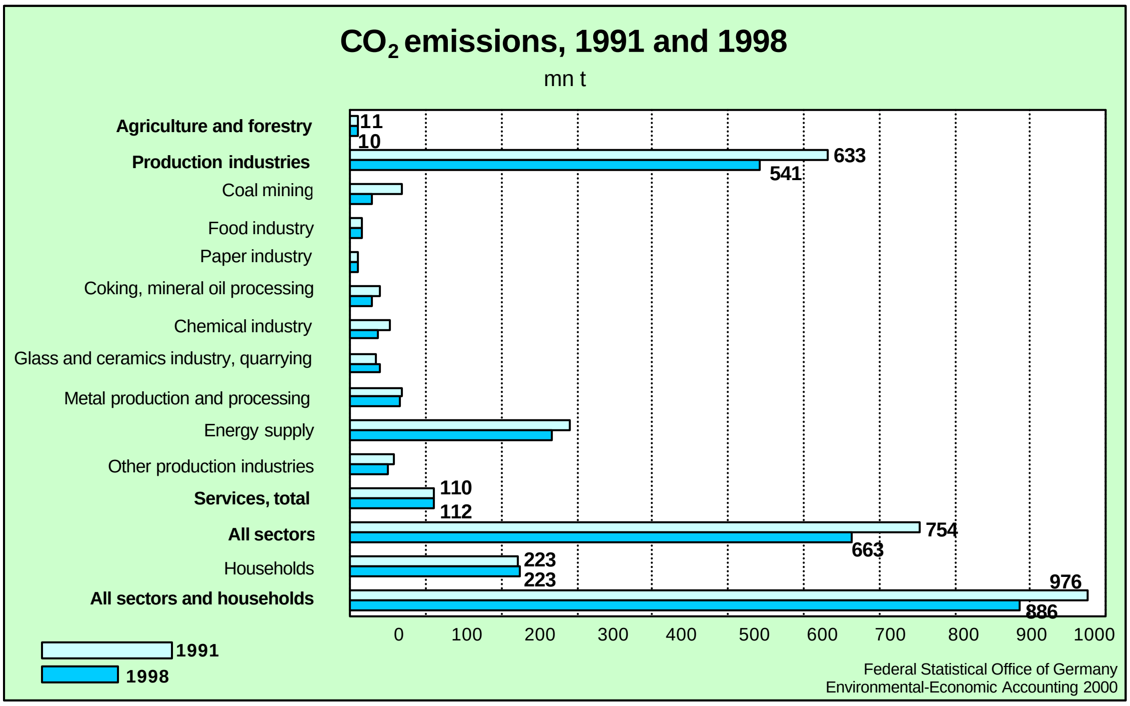
Direct emissions of the various air pollutants are calculated for the economic sectors and households by means of specific emission coefficients (database of the Federal Environmental Agency), energy consumption (database of the German Institute for Economic Research / energy balance) and by taking account of the processes running in the production sectors.

Direct emissions of carbon dioxide in Germany caused by economic activities amounted to 886.1 mn t in 1998 (figure 2). 662.8 mn t of that amount (74.8%) were discharged during the production of goods and services, while 223.3 mn t (25.2%) were created directly through the consumption activities of households. When broken down by purposes of final consumption of households, about two thirds (69 %) of the consumption-related emissions were caused through the use of emission-relevant energy sources for the purpose of "energy" (heating of buildings, hot water preparation, cooking), while one third (31%) was due to the utilisation of motor fuels for transport purposes. As regards production-related emissions, production industries accounted for four fifth, and the sector of "energy supply" for about half of them. The CO_2 emissions in the latter area are caused in particular by power generation. The sector of "glass and ceramics industry, quarrying" accounted for 5.9% of all production related emissions, the "chemical industry" for 5.6%. The share of "cooking, mineral oil processing" was 4.2%, while all service branches together had a share of 16.9%.

Between 1991 and 1998**,** direct CO_2 emissions decreased by 90.4 mn t (- 9.3%) to 886.1 mn t. The direct carbon dioxide emissions of households (consumption) rose slightly over the period examined (+ 0.8 mn t or + 0.4%), while the economic sectors(production) accounted for a decline by 91.2 mn t (- 12.1%).

The slight increase of emissions of households by 0.4% was contrasted by an 8.5% rise in price-adjusted final consumption expenditure of households. This shows that the trend of consumption expenditure of households and that of their direct CO_2 emissions has been decoupled. There are two effects explaining that development. About one third of it is due to the fact that the emission-relevant energy consumption per DM of final consumption of households decreased (- 2.1%) and about two thirds result from a decline in CO_2 emissions per energy quantity used (- 4.3%), i.e. the utilisation of energy sources containing less carbon (substitution of solid fuels by mineral oil and especially natural gas).

Figure 2: Emissions of carbon dioxide 1991 and 1998

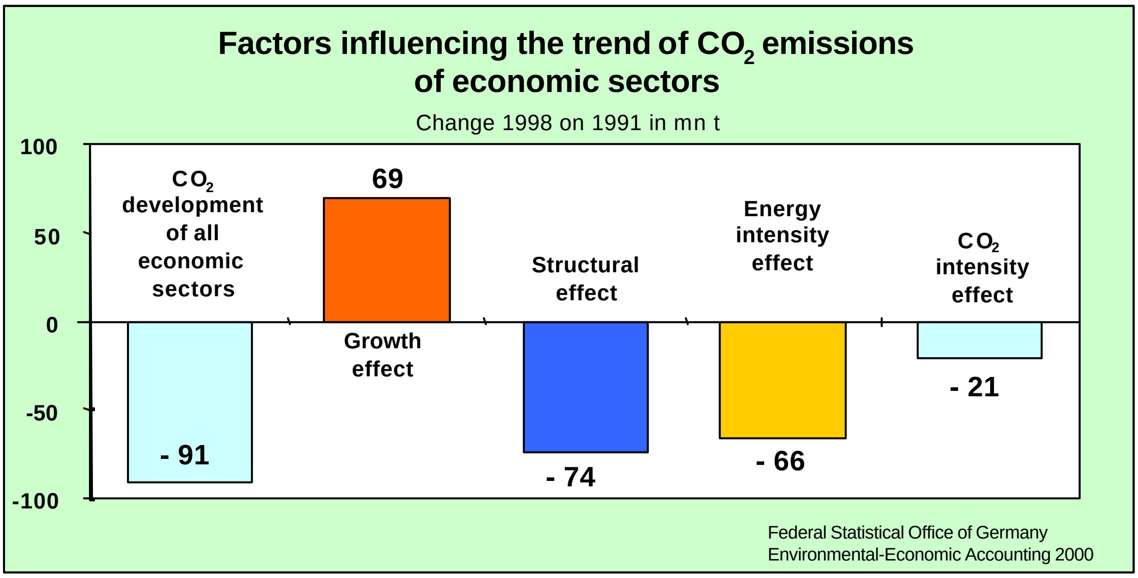


The direct emissions of carbon dioxide through production may be decomposed mathematically into various components, that is a growth effect, a structural effect, an energy intensity effect and a CO_2 intensity effect.[3] Those effects represent in model terms the mathematical influence of the individual components on the level of CO_2 emissions with the assumption that the other influencing factors remained unchanged. The growth effect represents the effect caused by the general increase in production. The structural effect covers the influence exerted by the changing economic structure (based on the breakdown of the economy by 60 sectors) on the CO_2 emissions. For example, the emission of carbon dioxide by the overall economy, with gross domestic product remaining constant, would be reduced if the share of relatively low-emission service sectors increased at the expense of emission-intensive sectors of production industries. The energy intensity effect (relation between the trend of emission-relevant energy consumption and real value added) may - with some reservations - be interpreted as a measure of the efficiency of energy use.[4] The CO_2 intensity effect (relation between the trend of CO_2 emissions and the emission-relevant energy quantity used) measures to what extent the emission of carbon dioxide was influenced by the change in the average carbon content of energy sources, e.g. by the use of lower-carbon and thus lower-CO_2 emission energy sources.

[3] As regards the methodological requirements (exogenous and independent character of the factors), the capacity of decomposition is limited, especially in the sphere of economic analysis; this has to be taken into account when interpreting the results. So, applying that method allows obtaining provisional information on the effects of various influences - e.g. on the trend of CO_2 emissions - by using relatively simple tools.
[4] Which, however, must not be confounded with energy productivity which is the reciprocal expression.

The mathematical decomposition of the entire decrease of carbon dioxide emissions in production by 91.2 mn t between 1991 and 1998 into the afore-mentioned components leads to the following result (figure 3): Due to the real growth of production (growth effect), CO_2 emissions would have to have increased by about 69 mn t compared with 1991. However, that influence was more than offset by the other factors. The largest contribution was made by structural change, i.e. the expansion of low CO_2-sectors and the shrinking of CO_2-intensive sectors, which contributed an estimated 74 mn t decline in emissions. More efficient energy use had an effect of - 66 mn t in mathematical terms. The growing use of low-carbon energy sources (e.g. natural gas) contributed 21 mn t to the decline in the overall production-related CO_2 emissions.

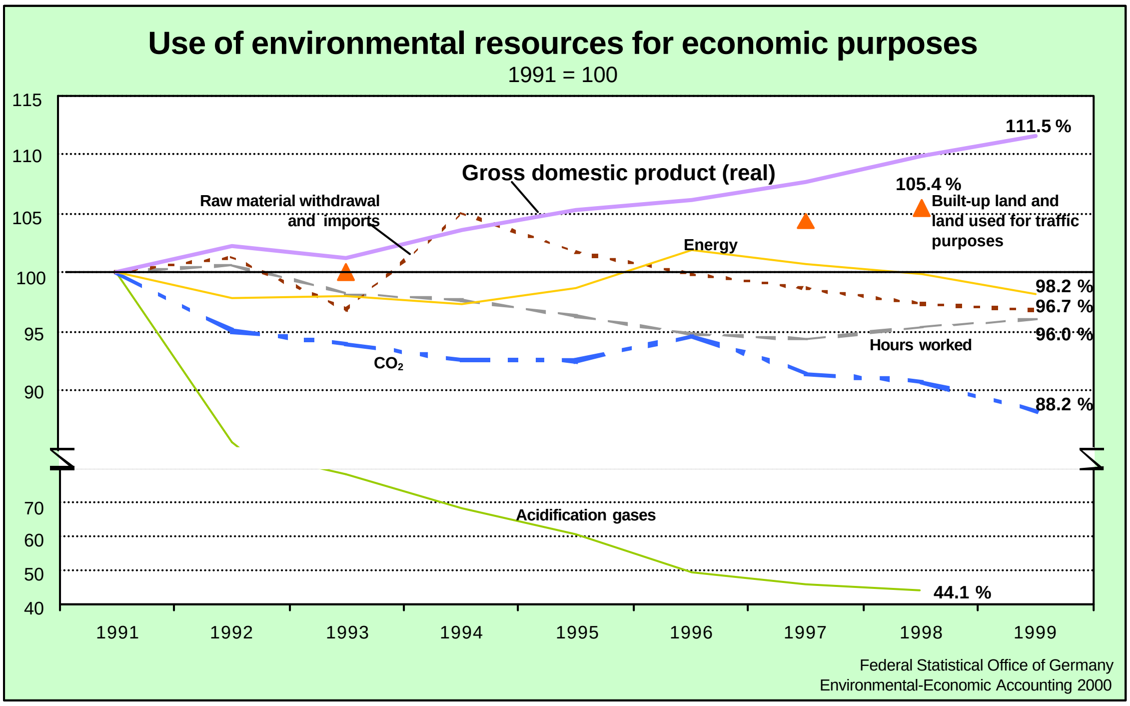
Figure 3: Factors influencing the trend of carbon dioxide emissions



3 Productivities of using nature

Figure 4 takes up both input factors explained in detail above and adds some other relevant input factors used for the calculation of productivity indicators in Germany. In order to compare eco-efficiency with "established" economic productivity measures the input factor of labour (hours worked) is included. The denominator of the productivity expressions - the GDP - is also shown. The figure pictures for all of these quantities the temporal development by setting the value of the year 1991 to 100.

Figure 4: Use of environmental resources for economic purposes



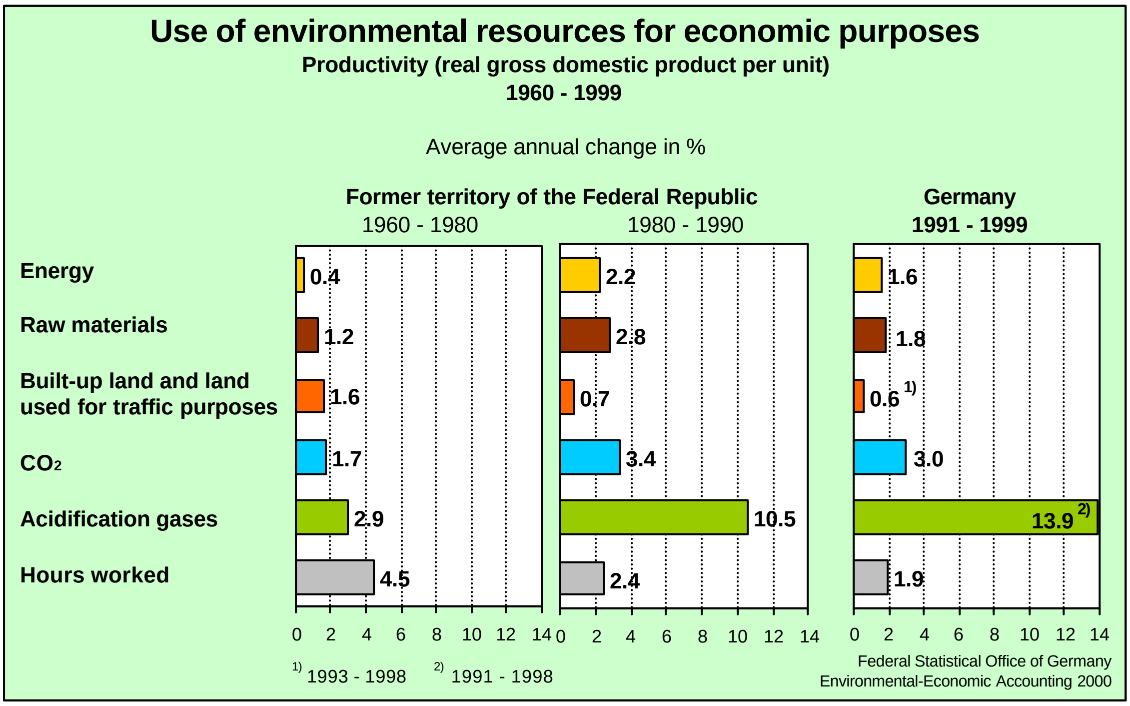
In Germany the development of the quantitative use of the individual natural factors was heterogeneous in the 1990s. Nature as a source of resources, in its function as a raw material and energy provider, was somewhat less heavily used in 1999 than in 1991. Raw material consumption was down 3.2%, energy consumption 1.8%. According to provisional estimates of the Federal Office of Building and Regional Planning for 1998, built-up land and land used for traffic purposes increased from 40 305 km^2 in 1993 to 42 495 km^2 in 1998 (+ 5.4%). That was an increase by 120 ha per day.

The use of nature as a sink for residuals and pollutants regarding air emissions has clearly decreased since 1991. Compared with 1990 (the reference year for the Federal Government's goal of reducing the emission of carbon dioxide) the discharge of carbon dioxide (CO_2) was down 15%. On the basis of 1991 - which for reasons of data availability is generally used as the reference year in this report -, this is a decrease of CO_2 emissions by nearly 12%. The discharge of acidification gases was down 56 % between 1991 and 1998.

When adjusted for price changes, the gross domestic product rose 11.5% between 1991 and 1999. This means that the pressure to use nature, which is caused by economic growth, developed rather moderately in the period observed. From 1991 to 1999 the number of hours worked fell 4.0%. Using the environment through carbon dioxide and acidification gas emissions was reduced even more strongly than using the factor of labour; however, savings achieved with regard to the energy and raw materials factors were clearly smaller than for the number of hours worked.

While these interpretations show how trends may be compared for different input factors it must also be noted each trend follows a "rather linear" curve; in most cases there are no rapid changes in development. If you had a look at the corresponding productivities for this period year by year, this would reveal little more than a fine tuning of eco-efficiency. If - on the contrary - a long-term examination is carried through the results are much more interesting (figure 5).

Figure 5: Long-term examination of productivities



The efficiency in using natural input factors - measured as the productivity, i.e. real gross domestic product per unit - increased for all factors examined, except for built-up land and land used for traffic purposes, in the period from 1960 to 1980; however, that increase was clearly smaller than in the last two decades. Comparing the last two decades with one another shows that the average development of productivity for the input factors examined was usually slower in the 1990s than in the 1980s. The average annual growth of energy productivity fell from 2.2% to 1.6%, the increase in raw material productivity slowed down from 2.8% to 1.8% and the average annual rise in area productivity decreased from 0.7% to 0.6%. Productivity growth regarding the use of nature as a sink for carbon dioxide fell from an average 3.4% in the 1980s to 3.0% in the 1990s. An exception is the corresponding growth in productivity for acidification gases, which in the 1990s (+ 13.9% per year) was larger than in the 1980s (+ 10.5%). If we take into account that for most of the indicators the increased efficiency in the 1990s was to a considerable extent due to unification-related special effects - such as large-scale close-downs in particularly environment-intensive branches or the conversion of plants in eastern Germany -, the data show a clear slowdown in productivity growth for the natural input factors.

The productivity trends for the individual environmental input factors however show only whether, and to what extent, the relevant factor is used more carefully than in the past. The indicator does not provide information on the extent to which the goal of sustainability has been reached. In order to fill this gap, targets were defined for some of the indicators mentioned here, i.e. CO_2 emissions, energy productivity, raw material productivity and area use. The target for the reduction of CO_2 emissions was defined by the Federal Government. The other targets were set up by the Federal Ministry for the Environment as part of developing the Environmental Barometer. These are the targets referred to also by the annual economic report 2000 of the Federal Government.[5] The first three targets will be dealt with more closely here.

Table 3: Selected indicators of the German Environmental Barometer

		1990	1992	1993	1998	1999
Energy productivity	mn DM/ PJ	219	239	237	255	263
	1990 = 100	100	109,1	108,2	116,4	120,0
CO_2-emissions	mn t	1 014	928	918	886	861
	1990 = 100	100	91,5	90,5	87,4	84,9
Raw material productivity	1993 = 100	-	-	100	108,1	110,3

According to the targets, CO_2 emissions should be reduced by 25% between 1990 and 2005. Energy productivity should double between 1990 and 2020 and for raw material productivity a 2.5-fold increase on the level of 1993 is envisaged for 2020.

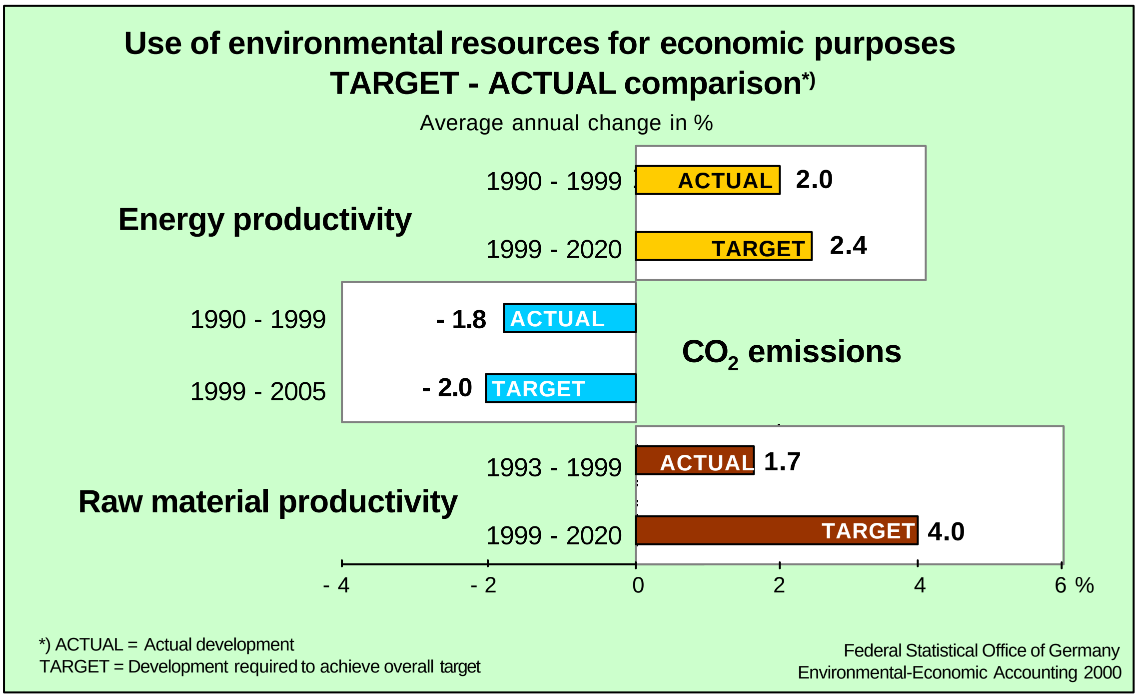
If we compare for the examined indicators the actual pace of development in the 1990s (figure 6, ACTUAL) with the target to be achieved over the next few years, which is required to arrive at the overall target, there is a considerable gap between the two. So the targets can be met only if we succeed in accelerating the development:

- Energy productivity rose about 20% between 1990 and 1999. This is an average annual increase of 2.0%. To meet the target set by the Federal Government, an average annual increase of 2.4% would be required until 2020.
- Actual CO_2 emissions fell by 153 mn t to 861 mn t between 1990 and 1999.[6] This is an average annual decrease by 17 mn t or 1.8%. More than half (86 mn t) of the total decrease of CO_2 emissions between 1990 and 1999 referred to the period 1990 to 1992. So for the period starting 1992 the average annual decrease was clearly smaller (9.6 mn t or 1.1%) than for the entire period. To meet the Federal Government's target (reduction to 760 mn t by 2005), CO_2 emissions into the environment in Germany would have to fall an annual 16.5 mn t or 2.0% in the years remaining until 2005 - that would be about the average of the past decade, but considerably more than the average of the years since 1992.
- Raw material productivity rose 10.3% from 1993 to 1999. This is an average annual increase of 1.7%. To meet the Federal Government's target for the increase of raw material productivity by 2020, an average annual growth of raw material productivity of 4.0% would be required for the years after 1999.

[5] *Bundestags-Drucksache* 14/2611 of 28 January 2000. See also: Environmental Barometer (*Umweltbarometer*) of the Federal Ministry for the Environment and the German Environment Index (*Deutscher Umweltindex - DUX*) derived from it. http://www.umweltbundesamt.de/dux/umweltbarometer.htm

[6] Data source: Federal Environmental Agency.

Figure 6: TARGET-ACTUAL comparison for selected indicators of the German Environmental Barometer



Selected publications about the German Environmental Economic Accounting

Gié, G., Leipert, C., Pasurka, C., Schäfer, D., Steurer, A.: Environmental Protection Expenditure and its Representation in National Accounts, in: K. Uno/P.Bartelmus: Environmental Accounting in Theory and Practice, Dordrecht/Boston/London 1998.

Hoffmann-Kroll, R., Benzler, A., Schäfer, D., Seibel, S.: Setting up National Biodiversity Monitoring for Nature Conservation in Germany – the Ecological Area Sampling (EAS). In: Schriftenreihe Landschaftspflege Naturschutz (Hrsg. Bundesamt für Naturschutz), Heft 62 (2000), S. 79ff.

Radermacher, W.: Sustainable Income: Reflections on the Valuation of Nature in Environmental-Economic Accounting, in: Statistical Journal of the United Nations ECE 11, 1994, p. 35 - 51.

Radermacher, W.: Indicators, Green accounting and environment statistics - information requirements for sustainable development, paper for the 51st Session of the International Statistical Institute, Istanbul, 18-26 August 1997.

Radermacher, W., Stahmer, C.: Material and Energy Flow Analysis in Germany - Accounting Framework, Information System, Applications, in: Uno, K., Bartelmus, P. (Ed.): Environmental Accounting in Theory and Practice, Dordrecht 1998.

Riege-Wcislo, W.: Implementation of SERIEE in Germany, Reporting year 1995, Eurostat project presented at the meeting of the working party „Economic Accounts for the Environment, 06. – 07.12.1999.

Riege-Wcislo, W., Heinze, A.: Empirical results and experiences for the estimation of selected nitrogen abatement cost curves in Germany; in: International Journal for Sustainable Development, 1 (1999), S. 95 ff.

Schoer, K.: Energy Use of Private Households by Purposes of Final Consumtion, paper for the Joint ECE / Eurostat Work Session on Methodological Issues of Environment Statistics, (Ma´ale Hachamisha (15 km from Jerusalem), Israel, 11-14 October 1999, (http://www.unece.org./stats/ducuments/1999.10.env.htm).

Schoer, K. and Flachmann, C.: Water flow accounts as part of material and energy-flow accounts in Germany, International Journal of Water, Vol. 2, No. 1.

Waldmüller, B.: Physical input-output tables of the Federal Statistical Office, paper for the Workshop of the ConAccount Material Flow Accounting Network, Stockholm, Sweden, 26-27 April 2001,