



# DIPLOMARBEIT

Titel der Diplomarbeit

„Structural Decomposition Analysis of Austrian Raw  
Material Consumption from 1995 to 2007“

verfasst von

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angestrebter akademischer Grad

Magister der Naturwissenschaften (Mag.rer.nat.)

Wien, 2013

Studienkennzahl lt. Studienblatt: A 444

Studienrichtung lt. Studienblatt: Diplomstudium Ökologie

Betreut von: Univ.-Doz. Dr. Helmut Haberl



## **Abstract**

The aim of this study is to quantify the effects of different driving factors of raw material consumption (RMC) in Austria. RMC is an indicator of domestic consumption that includes all materials used during production processes of traded commodities and allocates them to the destination of final demand. The three driving factors I focus on are production technology (i.e. material efficiency of production processes), the product mix of final demand (i.e. material intensity of consumption patterns) and the volume of final demand (i.e. the overall level of consumption activities, which is linked to economic growth). I further analyze if and to what extent improvements in technological efficiency and changing consumption patterns were able to offset increasing levels of overall consumption volume. I apply a structural decomposition analysis (SDA) to determine how these factors contributed to changes in RMC for Austria between 1995 and 2007. By breaking down the results into different material categories, final demand categories and time periods, I show their respective impact on overall RMC changes. The results show that more efficient production technology and a less material-intensive product mix partly compensated for an increasing volume of final demand. However, decoupling trends varied significantly across material categories and time periods. Another interesting finding was that the highest rate of RMC increase occurred during the period with the lowest rate of economic growth. This was caused by a shift in consumption patterns towards more material-intensive products as well as a significant drop in material efficiency of biomass-related production processes. In order to achieve absolute decoupling of material consumption and economic growth, efficiency gains due to improved production technology and more sustainable consumption patterns have to increase at much higher rates than observed during the studied period.

## **Introduction**

According to data from UNEP's International Resource Panel (IRP), the global rate of material extraction rose significantly during the last century and is still doing so (UNEP

2011). There is a growing consensus that an absolute decrease in resource use and its associated environmental impacts is required on a global level in order to allow for sustainable development (EC 2011; UNEP 2011; OECD 2012). Current rates of per capita resource consumption are unequally distributed (Steinberger et al. 2010; UNEP 2011). Therefore, emerging economies are generally not expected to decrease their material consumption rates, but instead focus on policies that promote economic growth. On the other hand, industrialized countries, such as Austria, generally have relatively high levels of material consumption. Since their level of per capita consumption could not be transferred to the rest of the world without seriously compromising the natural resource base even further, industrialized countries are urged to bring their consumption rates down to more sustainable levels.

A crucial question is whether and how a decrease in resource use can be achieved while maintaining positive growth rates of economic activity. Although the link between GDP and human well-being is being disputed within the scientific community and some supranational organizations (Victor 2008; Stiglitz et al. 2009; Jackson 2009; EC 2009), the goal of economic growth is usually not questioned on the national policy level. In order to decouple material use from economic growth in absolute terms, material efficiency – which is the economic output produced per unit of materials – has to increase faster than GDP. However, the general trend so far has been one of relative decoupling at best (UNEP 2011). The rate at which material use is increasing is lower than that of economic growth, but material use is still rising in absolute terms.

The material efficiency of an economy is affected by two main factors. Production technology determines how efficiently materials are used in the production process, including substitution of certain materials with others. The product mix describes the relative composition of consumption and can be positively affected by a “selective degrowth” of material-intensive sectors and an increase in the importance of material-efficient service sectors (Van den Bergh 2011). Both of these factors have to be considered when striving for a dematerialization of economic activities. In addition, the role of international trade has to be considered as well. There has been a general trend of more advanced economies shifting the material use and environmental burdens associated with their consumption activities to other countries (UNEP 2011;

Bruckner et al. 2012). Consumed goods often contain significant amounts of “embodied” resources; that is, resources which were used to produce those goods abroad. In order to assign this resource use to the destination of final consumption, the respective indicator of material consumption has to take these indirect imports into account. One indicator that is able to do so is raw material consumption (RMC).

RMC is a consumption based indicator derived from material flow accounts (MFA) (Eurostat 2001; Weisz 2006). Unlike standard production based MFA indicators such as domestic material input (DMI) or domestic material consumption (DMC), consumption based indicators include upstream material flows used in the production process of traded goods and assign them to the importing country (Schaffartzik et al. 2013). These upstream material requirements are usually termed Raw Material Equivalents (RME). Schaffartzik et al. (2013) show in their results, that Austria’s RMC exceeds its DMC by 15%. The biggest differences were observed in the consumption of metal ores.

The aim of this study is to quantify the effects of these driving factors – production technology, final demand mix and final demand volume – on raw material consumption (RMC) in Austria. Furthermore, this study aims to address how these effects vary among different material categories, final demand categories and economic sectors. The analysis was done by applying a structural decomposition analysis (SDA) to environmentally extended input-output-tables (EE IO) derived from a previous study by Schaffartzik et al. (2013). The EE IO study by Schaffartzik et al. (2013) calculated the RMC for Austria on a yearly basis 1995-2007. Note that this study uses data from Material Flow Accounting (MFA) and thus focuses on material use.

While decomposition analysis has been widely applied to energy issues for decades (Ang and Zhang 2000; Su and Ang 2012), the combination of decomposition analysis and MFA is a rather new field of research. Hoffrén and Luukkanen (2000) were the first to do so, using index decomposition analysis (IDA) to analyze Finnish material flows. Hashimoto et al. (2008) looked into Japanese resource productivity using IDA as well. Muñoz and Hubacek (2008) applied SDA to the DMI of Chile, while Wood et al. (2009) decomposed both the DMI and total material requirement (TMR) of Australia using SDA. In both, Chile and Australia, exports play a significant role. Therefore, the authors

decomposed exports separately from domestic consumption. Thus, a comparison of these results to the study presented here is not straightforward. The study of highest comparability was conducted by Weinzettel and Kovanda (2011), who were the first to introduce the RMC indicator to SDA. Their country of interest, the Czech Republic, is adjacent to Austria and since 2004 also a member of the European Union. In the Czech Study, the same three decomposition factors were used, although they were named differently. However, compared to Weinzettel and Kovanda (2011), the Austrian study presented here differs in that (1) the time period is broken down into three shorter periods, (2) material categories are higher aggregated, (3) a different decomposition method is used and (4) the economic situation in these two countries differs with the Czech Republic undergoing significant changes after acceding the EU (Kovanda et al. 2010).

## Methods

### Environmentally extended input-output model

This study is based on calculations of Austria's RMC made by Schaffartzik et al. (2013), who compiled environmentally extended input output tables by combining MFA data with supply and use tables. Following the domestic technology assumption, this approach generally assumes that imports are produced with the same technology as domestic production. Schaffartzik et al. (2013) extend this IO approach by coefficients derived from life-cycle inventories for those imports where the domestic production technology is not representative. This hybrid approach is then applied to calculate the RMC as well as other RME based indicators.

The general static IO equation is

$$x = Ax + y \quad (1)$$

Solving for  $x$  therefore results in

$$x = (I - A)^{-1} \cdot y = L \cdot y \quad (2)$$

where  $x$  is a vector of total output of the economy,  $y$  is a vector of final demand,  $A$  is a  $(n \times n)$  matrix of inter-industry technology coefficients of  $n$  sectors,  $I$  is the identity matrix and  $L$  is the Leontief Inverse matrix  $(I - A)^{-1}$ . (Miller and Blair 2009)

Schaffartzik et al. (2013) used MFA data for Austria compiled by Statistik Austria (Statistik Austria 2012a, 2012b) and linked this MFA data to the IO tables in the form of a  $(k \times n)$  matrix of material intensity factors  $F$  for  $k$  material categories. This yields an environmentally extended input output table and a  $(k \times n)$  matrix of total material requirements  $E$ :

$$E = F \cdot L \cdot y \quad (3)$$

By applying a hybrid IO-LCA approach to obtain the RMC, equation (3) has to be adapted in the following way:

$$RMC = F' \cdot L \cdot y_d \quad (4)$$

where  $F'$  is an adapted matrix of material factors including LCA data for sectors with non-representative production technology, and  $y_d$  is the domestic final demand, which is total final demand  $y$  minus exports  $y_{ex}$  (for details see Schaffartzik et al. 2013).

### Structural Decomposition Analysis

Structural decomposition analysis is a comparative method to explain changes of any variable between two points in time or space<sup>1</sup>. By decomposing the respective variable into separate factors, I can then determine how these driving factors contributed to changes in the variable. Over the last decades, SDA was applied to a wide variety of environmental indicators, ranging from energy and emissions to materials. For a good overview of previous SDA studies see Hoekstra and Van den Bergh (2002) and Su and Ang (2012)<sup>2</sup>. In this study, the indicator I want to decompose is RMC.

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<sup>1</sup> For examples and discussions on SDA used for cross-country comparison see Ang and Zhang (1999), Zhang and Ang (2001), Alcantara and Duarte (2004) and Gingrich et al. (2011).

<sup>2</sup> Note that Su and Ang (2012) do not cover any studies applying SDA to material indicators.

## Decomposition factors

If we want to decompose RMC we first need to determine the underlying driving factors (hereafter also called effects) that we are interested in. All these effects can be derived from the environmentally extended input-output model in equation (4). Depending on the focus of research, the factors in equation (4) can be further decomposed or even combined. Following Weinzettel and Kovanda (2011) I decided to decompose RMC into three effects:

$$RMC = T \cdot M \cdot G \quad (5)$$

$T$  is a combined technology effect represented by a set of conversion factors from final demand into induced material flows (Weinzettel and Kovanda 2011) ( $T = F' \cdot L$ ). In most SDA studies  $F$  and  $L$  are analyzed as separate effects (Muñoz and Hubacek 2008; Wood et al. 2009; Weber 2009; Wachsmann et al. 2009) and it might seem counterintuitive to aggregate two factors, as the general intent of an SDA is to decompose an indicator into more effects. Decomposing the production side of the RMC indicator into both  $F$  and  $L$  would allow to distinguish between changes in material intensity ( $F$ ) and changes in the economic structure, e.g. through changes in the supply chain or substitution between different material inputs ( $L$ ). However, I am more interested in the aggregate effect of overall technology, an approach also used by Weinzettel and Kovanda (2011), mainly for ease of interpretation. The combined factor  $T$  can be interpreted as a direct material intensity factor  $F$  adjusted by indirect inputs  $L$ , thus yielding conversion factors from any amount of domestic final demand for industry products  $i$  to total (i.e. direct and indirect) material input  $k$  (Lenzen 2001).

While  $F$  and  $L$  were aggregated to one production technology effect  $T$ , I decomposed  $y_d$  into a final demand mix effect  $M$  and a final demand volume effect  $G$ .  $M$  is a ( $n \times d$ ) matrix of industry outputs  $n$  consumed by each final demand category  $j$  relative to its total final demand volume ( $M = y_{d_{n,j}}/y_{d_j}$ ). This effect depicts changes in consumption patterns by revealing the relative mix of products consumed by each final demand category. This indicates whether a society is shifting towards less material-intensive consumption patterns.  $G$  is a vector of total final demand volume of



final demand categories  $j(y_{d_j})$ . It shows the impact of increases in overall consumption levels on RMC. Since domestic final demand excludes exports, this effect represents gross national expenditure (GNE) rather than gross domestic product (GDP) ( $GNE = GDP - exports$ ). However, the link between GNE and GDP is strong enough that this volume effect can be considered as reflecting economic growth.

Other SDA studies further decompose final demand into a population effect and a final demand destination effect<sup>3</sup> (Wood et al. 2009; Wood 2009; Wachsmann et al. 2009), both of which are not considered relevant for this study due to the following reasons: While population growth can be an important factor in countries with significant population growth rates during the studied time period – e.g. Brazil (Wachsmann et al. 2009) or Australia (Wood et al. 2009) – it is negligible in the case of Austria. Therefore, population was not considered as a separate effect in this study, but instead is part of the final demand volume effect ( $G$ ). The final demand destination or category effect shows how the indicator is affected by shifts in the relative contribution of different final demand categories  $j$  to total final demand  $y$  ( $Y_{cat} = y_j/y$ ). Hence, it can be used to calculate the impact of shifting shares between exports and domestic final demand, which is often relevant for export-oriented countries (e.g. Muñoz and Hubacek 2008). Since the RMC indicator excludes exports as a final demand category, this distinction is obsolete for this study. The final demand destination effect would instead show changes caused by shifts in relative demand/consumption volumes of the four domestic final demand categories ( $Y_{d_{cat}} = y_{d_j}/y_d$ ). However, this factor on its own only had a very small effect to indicator changes in recent similar studies (e.g. Wachsmann et al. 2009; Wood et al. 2009). Furthermore, this SDA was done for each of the four aggregated domestic final demand categories separately. This allows for a more detailed analysis of the contribution of each final demand category to the different effects than the final demand destination effect would show on its own.

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<sup>3</sup> Other studies also refer to the final demand destination effect as category or international trade effect (Muñoz and Hubacek 2008).

## Decomposition Method

After defining the effects in which I am interested in, I quantify the respective contribution of these factors to changes in RMC. For this purpose, several decomposition methods have been developed over the years. Hoekstra and Van den Bergh (2002) give a good overview of methodological developments in SDA until 2001. Su and Ang (2012) discuss most recent methodological developments in studies applying SDA to energy and emission indicators and show that the D&L method (Dietzenbacher and Los 1998) and the logarithmic mean Divisia index (LMDI) method (Ang and Choi 1997; Ang and Liu 2001) were the two most used decomposition methods in most recent SDA studies. Recent studies applying SDA to material flow indicators confirm this trend (e.g. Muñoz and Hubacek 2008; Wood et al. 2009; Weinzettel and Kovanda 2011).

Following the general framework presented by Su and Ang (2012) for when to apply D&L or LMDI in an SDA setting, both of these methods meet the criteria of this particular study equally well. I decided to apply the LMDI method, mainly for its ease of use. While D&L still remains the most common decomposition method in SDA, LMDI was applied more and more frequently in recent years (Su and Ang 2012). This is at least to some extent due to the fact that difficulties handling zero-values – arising from LMDI's use of the logarithmic mean and  $\ln(0)$  not being defined – meanwhile have been solved by Ang and Liu (2007a) as well as Wood and Lenzen (2006). They recommend using limits for logarithmic terms containing zero-values, an approach I also used for handling negative numbers in the data set (Ang and Liu 2007b).

Unlike other decomposition methods, LMDI gives perfect decomposition (i.e. does not leave a residual term) and is consistent in aggregation (i.e. decomposition can be performed at the sub-group level and then be aggregated) (Ang and Liu 2001; Ang 2004). See Annex for more detailed information on methodological developments in the field of decomposition analysis and LMDI in particular. Following the LMDI formulation process in Ang (2005), the general identity for RMC is given by

$$RMC = \sum_i RMC_i = \sum_i T_i, M_i, G_i \quad (6)$$

where sub-script  $i$  stands for different material categories and the right-hand side of the equation consists of the contributing factors. When decomposing changes in  $RMC_i$  from base year 0 to terminal year  $t$  using additive decomposition, the difference has to be used:

$$\Delta RMC = \sum_i \Delta RMC_i = \sum_i RMC_i^t - RMC_i^0 = \sum_i \Delta RMC_{Ti} + \Delta RMC_{Mi} + \Delta RMC_{Gi} \quad (7)$$

The terms on the right-hand side are changes in RMC assigned to the different factors. In order to calculate the effect of each individual factor on changes in RMC, the LMDI approach uses the general formulation (Ang 2004, 2005):

$$\Delta V_{xk} = \sum_i L(V_i^t, V_i^0) \ln \left( \frac{x_{k,i}^t}{x_{k,i}^0} \right) = \sum_i \frac{V_i^t - V_i^0}{\ln V_i^t - \ln V_i^0} \ln \left( \frac{x_{k,i}^t}{x_{k,i}^0} \right) \quad (8)$$

where  $L(a, b) = (a - b)/(\ln a - \ln b)$  and  $\Delta V_{xk}$  are changes in the aggregate  $V$  due to factor  $x_k$ .

When this formula is applied to the three effects under research, the respective formulae are:

$$\Delta RMC_{Ti} = \sum_i \frac{RMC_i^t - RMC_i^0}{\ln RMC_i^t - \ln RMC_i^0} \ln \left( \frac{T_i^t}{T_i^0} \right) \quad (9)$$

$$\Delta RMC_{Mi} = \sum_i \frac{RMC_i^t - RMC_i^0}{\ln RMC_i^t - \ln RMC_i^0} \ln \left( \frac{M_i^t}{M_i^0} \right) \quad (10)$$

$$\Delta RMC_{Gi} = \sum_i \frac{RMC_i^t - RMC_i^0}{\ln RMC_i^t - \ln RMC_i^0} \ln \left( \frac{G_i^t}{G_i^0} \right) \quad (11)$$

## Data

This study is based on data derived by Schaffartzik et al. (2013), who calculated the raw material consumption (RMC) for Austria from 1995 to 2007 on a yearly basis<sup>4</sup> using a hybrid approach, which combines input-output (IO) tables and life-cycle inventories. The underlying physical data are material use compiled in MFA (for a description of methods see Eurostat 2001 and Eurostat 2012). MFA data cover material extracted domestically (Domestic Extraction) as well as direct imports and exports in metric tons per year. Materials are grouped in material categories, most commonly in four main categories: biomass, metal ores, non-metallic minerals and fossil energy carriers. MFA data for Austria are compiled by Statistik Austria on a yearly basis (Statistik Austria 2013a, 2013b).

Based on this data set I applied a structural decomposition analysis (SDA) on the RMC indicator for the four main material categories (i.e. biomass, metal ores, non-metallic minerals and fossil energy carriers). Note that a fifth material category was originally decomposed as well. This material category „Other“ (Schaffartzik et al. 2013) accounts for those products whose main fraction cannot be assigned to only one of the four basic material categories. Since the impact of this category is so insignificantly small, it is not further discussed in this paper. The applied decomposition method allows simple aggregation of these categories to obtain results for the total amount of materials as well. Note that results for total RMC still contain the material category “Other”. Furthermore, domestic final demand was split into four final demand categories which were derived and combined from the underlying IO tables.

The studied time period, lasting from 1995 to 2007, was further split into three shorter periods: 1995 to 2000, 2000 to 2005 and 2005 to 2007. This allows to take a closer look at different stages of the economic cycle and the link to physical flows. Due to differences in sector disaggregation in IO tables before and after 2000, the IO table for the year 2000 had to be adapted to the level of disaggregation of the 1995 IO table in order to conduct an SDA from 1995 to 2000. Since the agricultural sector was further disaggregated into agriculture, forestry and fisheries in IO tables from 2000 onwards I

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<sup>4</sup> except for the years 1996 and 1998, which were not covered

aggregated these three sectors in the 2000 IO table and material intensities were adjusted accordingly. For the time period from 2000 to 2005 the original 2000 IO table was used. In order to exclude inflationary effects all current prices in IO tables were deflated to 1995 constant prices using price indices from Statistik Austria (2013a).

## Results

Austria's material consumption was decoupling from economic growth in recent years and thus resource efficiency was increasing. However, material use was only relatively decoupled from economic growth with resource efficiency growing at smaller rates as compared to GDP. The decomposition analysis shows that the growth in final demand volume (GNE<sup>5</sup>) resulted in an increase of total raw material consumption (RMC) in all categories (Fig. 1). Final demand mix and technology on the other hand were mostly decreasing material use.

For biomass, this decreasing effect of final demand mix and technology even offset the increase in RMC attributed to final demand volume. This means that, although the Austrian society has consumed more overall in monetary terms, a decrease in the relative share of biomass-intensive products in the final demand mix and a more efficient production technology compensated for that increased consumption. Thus, absolute decoupling of biomass consumption and GNE has been achieved, at least to a slight extent.

Metal ores, on the other hand, behave differently. Both the technology and the final demand mix effect resulted in a slight increase in the consumption of metal ores. When added to the increase induced by final demand volume, metal ore consumption rose even faster than GNE. Therefore, metal ores show no decoupling trend at all.

For non-metallic minerals, there was a significant trend towards a less material-intense product mix of consumption. If production technology had improved at nearly the same rate, this would have easily offset the increased final demand volume. However,

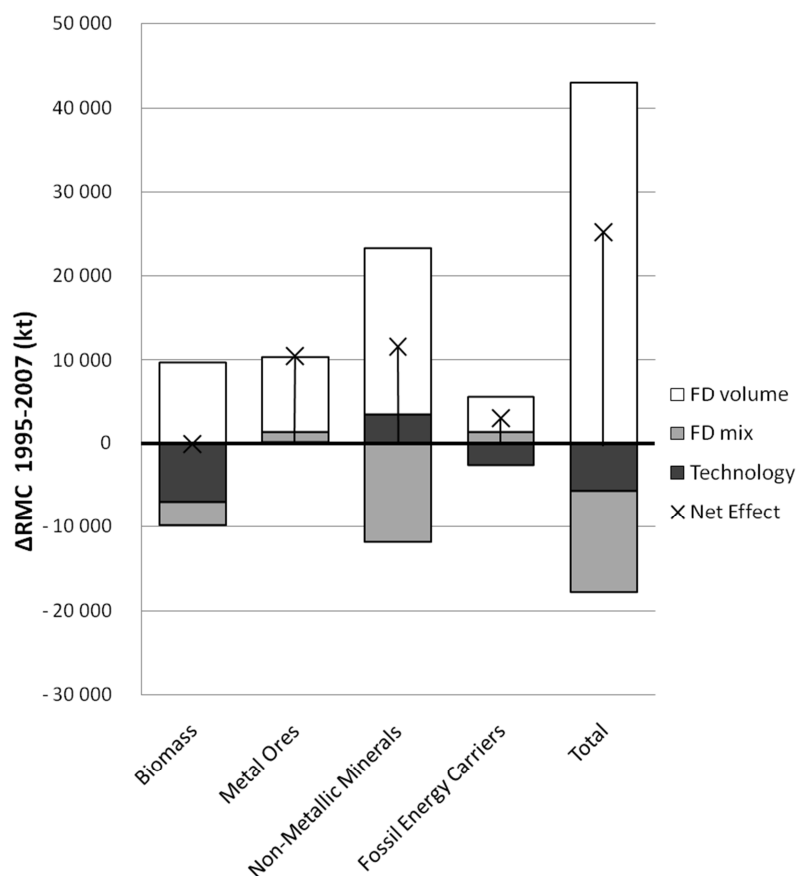
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<sup>5</sup> Note that  $GNE = GDP - \text{exports}$

production technology became less material-efficient. Overall, though, the final demand mix had a stronger effect than production technology. Thus, the consumption of non-metallic minerals was still decoupling from GNE in relative terms.

The results for fossil energy carriers are similar to those for non-metallic minerals, only that in this case the production technology became more efficient, while the share of products containing fossil-energy carriers (directly or indirectly) in the consumption mix increased. Technology and final demand mix combined still lead to a decrease in material intensity, thus showing relative decoupling.

When adding up all material categories, total RMC shows relative decoupling as well. Both production technology and final demand mix contributed to an improvement in material efficiency. However, in order to compensate for the increase in final demand volume (GNE) these efficiency gains would have to be far higher. Thus, total RMC has still increased significantly during the studied time period.



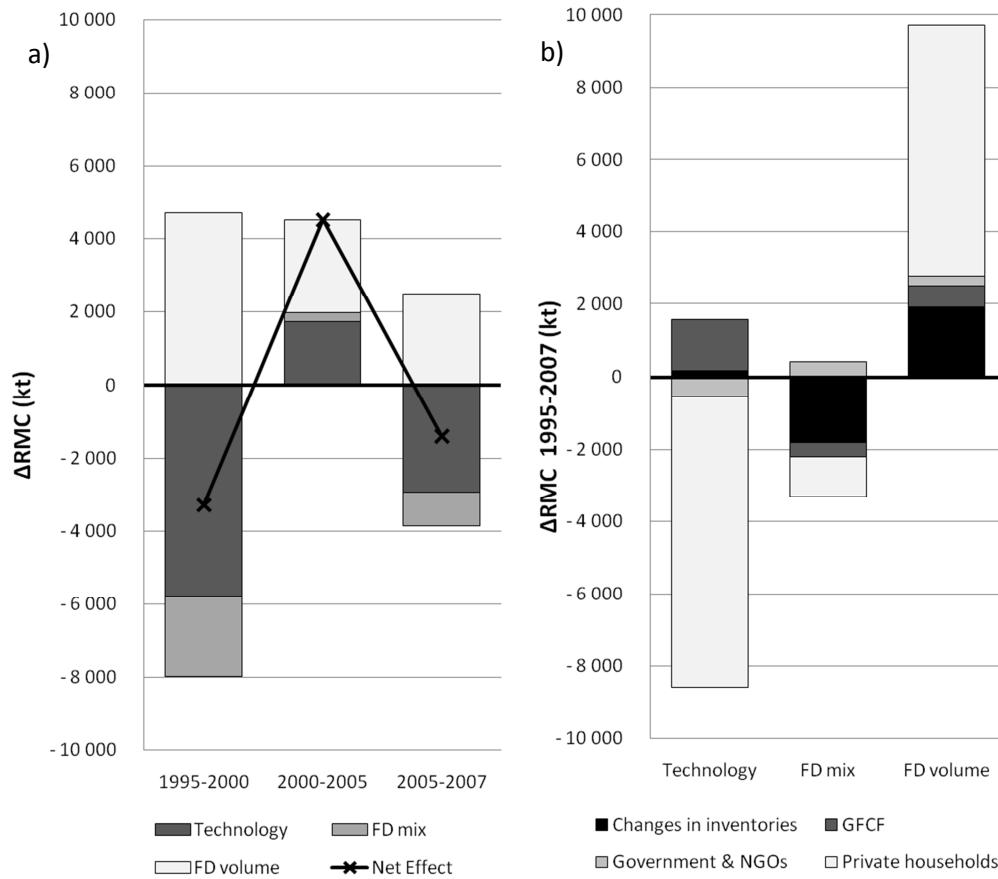
**Figure 1** Decomposition of changes in raw material consumption (RMC) from 1995 to 2007 into the effects of final demand (FD) volume, final demand mix and technology in kt. The respective net effect is the sum of all three effects.

In addition, this study breaks down the results for total RMC as well as all material categories into three time periods: 1995-2000, 2000-2005, 2005-2007<sup>6</sup> (Fig. 2-6). This allows for comparisons not only between these time periods but also with other studies, which often analyzed results for five-year periods. Another objective of this study is to show the results for the whole time period disaggregated to different final demand categories (Fig. 2-6). This illustrates the impact of each final demand category on different effects for the respective material category. However, before going into the results for the final demand categories I first have to clarify the link between final demand categories and the technology effect. One would assume that final demand categories have no direct influence on production technology. However, increased technological efficiency induced by final demand categories can be interpreted in that those sectors, which are mainly producing for the respective final demand category, have become more material-efficient.

First, biomass shows a very varying trend over the different time periods (Fig. 2). While final demand volume has an increasing effect on RMC throughout all periods, technology and final demand mix fluctuate between a significantly decreasing effect during the first and the most recent period and an increasing effect during the second period. Regarding the impact of final demand categories on the different effects, we can see that changes in private household consumption had the biggest impact on biomass RMC. Household consumption was mainly responsible for the increase in volume of final demand and the decrease in biomass intensity of production technology. Changes in inventories have also been important for changes in the final demand mix and volume.

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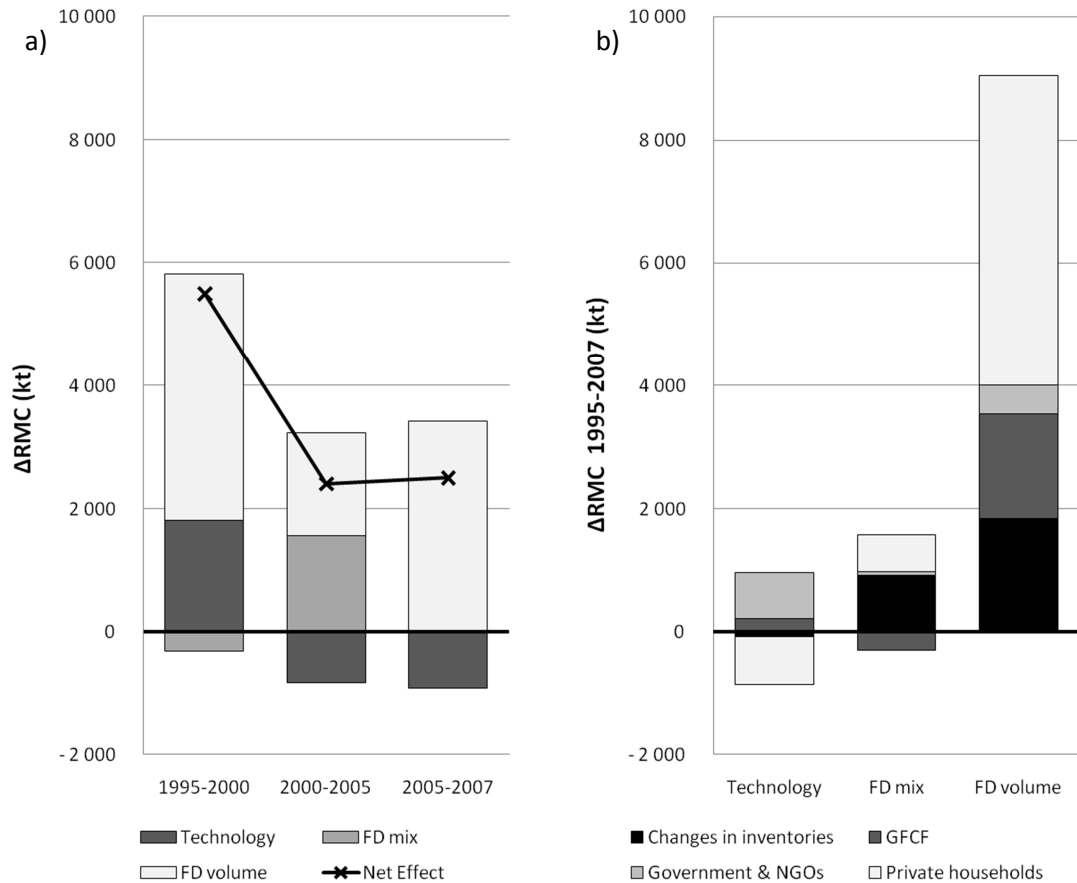
<sup>6</sup> The third time period is covering only changes over 2 years, 2005 to 2007, due to the available time series of the underlying RMC data (Schaffartzik et al. 2013)



**Figure 2** Decomposition of changes in raw material consumption (RMC) for biomass, disaggregated to a) different time periods and b) different final demand categories. [kt]

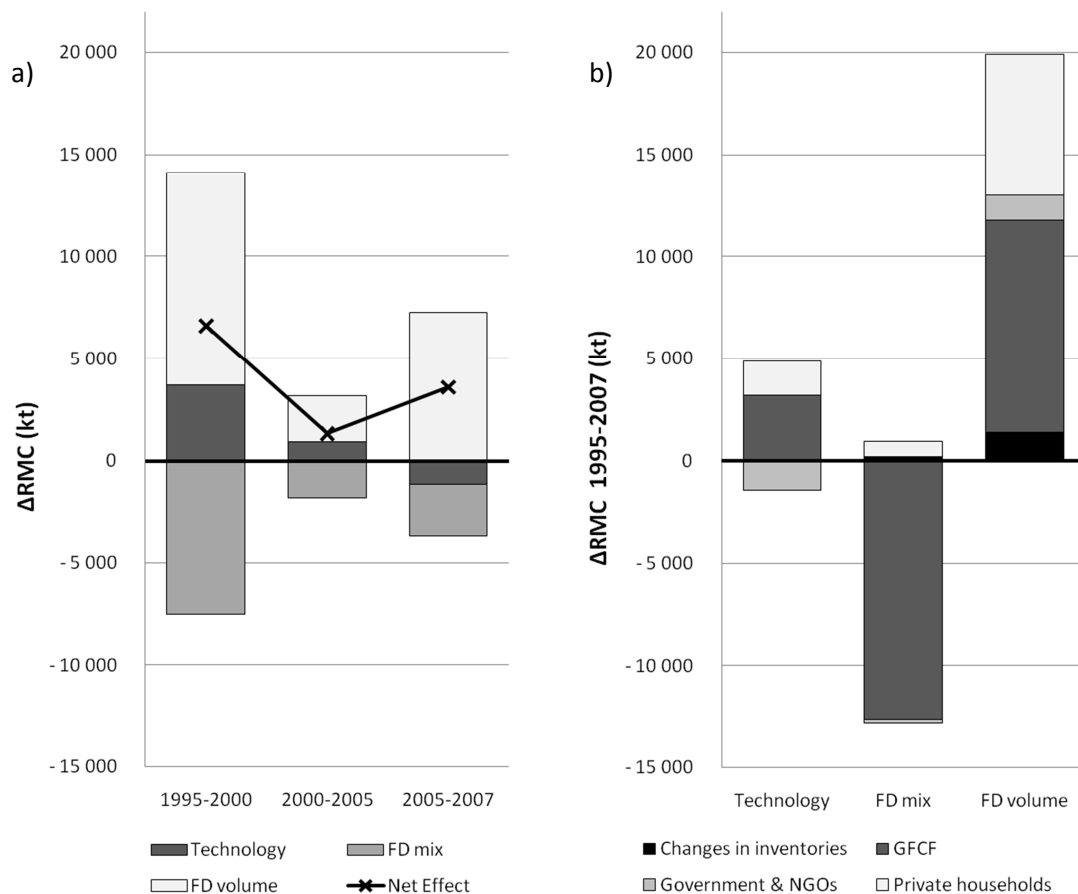
For metal ores the production technology changed from having an increasing effect on RMC during the first period to a decreasing effect during more recent periods (Fig. 3). The final demand mix effect significantly increased RMC from 2000 to 2005. At the same time, the increasing effect of growing final demand volume was considerably lower during this period. Efficiency gains in production technology due to private household consumption were offset by increasing effects of consumption by the government and NGOs. While private household consumption played the most important role regarding changes in the consumption of metal ores, gross fixed capital formation (GFCF) and changes in inventories had a significant increasing effect on final demand volume and in the case of inventory changes also on the final demand mix.





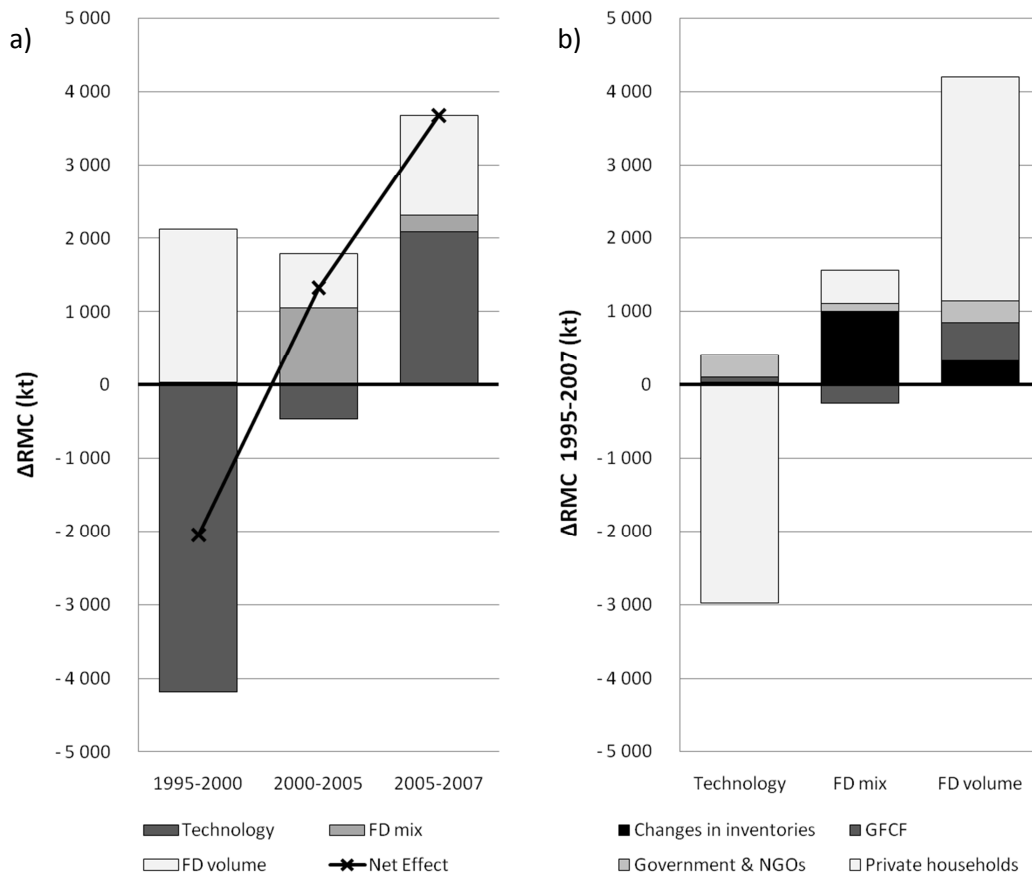
**Figure 3** Decomposition of changes in raw material consumption (RMC) for metal ores, disaggregated to a) different time periods and b) different final demand categories. [kt]

Non-metallic minerals also show a lower volume effect during the second period compared to other periods (Fig. 4). Production technology had an increasing effect on RMC from 1995 to 2005. It was not until the last two years that technology became more efficient. The final demand mix always had a decreasing effect, although this effect was significantly larger during the first period. The contribution of different final demand categories shows the important role of GFCF for non-metallic minerals. It contributed to an increase in material-intensity of production technology and was almost entirely responsible for the crucial decrease caused by the final demand mix effect. Regarding the volume effect, private household consumption was the most important final demand category besides GFCG.



**Figure 4** Decomposition of changes in raw material consumption (RMC) for non-metallic minerals, disaggregated to a) different time periods and b) different final demand categories. [kt]

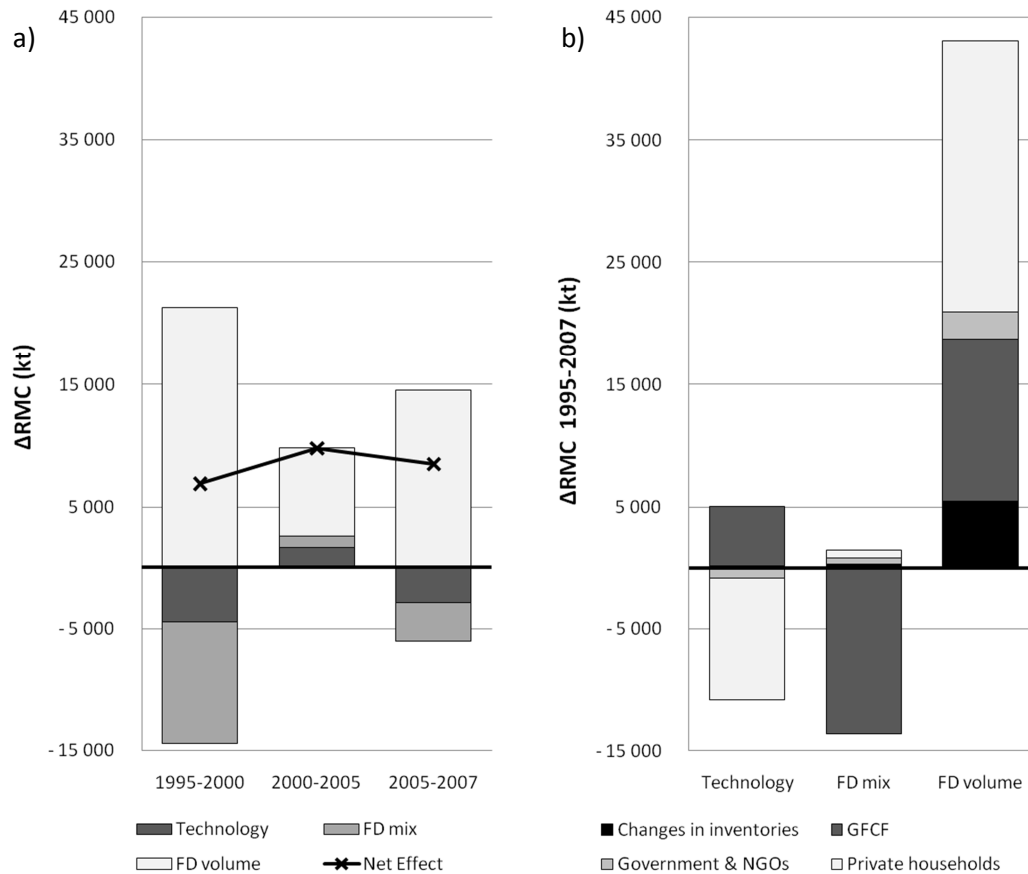
Regarding changes of the volume effect over time, fossil energy carriers show similar trends as the other material categories (Fig. 5). Again, the volume effect was considerably smaller from 2000 to 2005. The technology effect shows a substantial variation. While technology had a decreasing effect on the RMC of fossil energy carriers overall, the results reveal that significant efficiency gains during the first period were followed by opposite trends during more recent years. The mix effect led to a substantial increase in RMC during the second period from 2000 to 2005. Private household consumption is by far the most important final demand category for fossil energy carriers, with inventory changes also contributing considerably to increases due to the final demand mix effect.



**Figure 5** Decomposition of changes in raw material consumption (RMC) for fossil energy carriers, disaggregated to a) different time periods and b) different final demand categories. [kt]

Adding up all material categories gives us the results for total RMC changes (Fig. 6). The first and the most recent period both show similar trends of decreasing technology and final demand mix effects partly offsetting the effects of increasing final demand volumes. Note that the most recent period is shorter, thus explaining the lower magnitude of all effects compared to the first period. The second period, however, differs quite significantly. While the final demand volume effect was lower compared to other periods, technology and final demand mix both had an increasing effect on total RMC. Breaking total RMC down into final demand categories shows that increases in final demand volume were mainly driven by private household consumption and GFCF, with inventory changes having an increasing effect as well. GFCF caused an increase in material-intensity of production technology. This effect was more than offset by private household consumption though. The only final demand category that had a significant impact on the final demand mix effect was GFCF. This decreasing effect is mainly caused by non-metallic minerals, which make up

the largest part of total RMC. Consumption from government and nongovernmental organizations (NGOs) generally contributed very little to the different effects.



**Figure 6** Decomposition of changes in total raw material consumption (RMC), disaggregated to a) different time periods and b) different final demand categories. [kt]

Changes in inventories play an important role for the volume effect of biomass and metal ores as well as for the mix effect of biomass, metal ores and fossil energy carriers. It can be argued that inventory changes as a final demand category do not reflect current but future consumption. Therefore, a decrease in the mix effect caused by changes in inventories can potentially hide an actual increase in the material intensity of current consumption patterns. For example, increases in biomass RMC from 2000 to 2005 due to the mix effect would be even higher if inventory changes were not taken into account. For this period, changes in inventories decrease the mix effect for biomass by -1.5 Mt, of which -1.3 Mt are originating from forestry. The increasing effect of inventory changes on the mix effect for fossil energy carriers might appear to be undesirable, since a decreasing mix effect is considered to contribute to

sustainable consumption. However, increasing inventory changes of fossil energy carriers imply that these resources have been stocked instead of consumed. Thus, the impact of inventory changes on different effects has to be interpreted in a different way than for other final demand categories.

## Discussion

The results clearly show that overall consumption volume, which is linked to economic growth, has been the main driver of increases in material consumption. This confirms the findings of other studies (Muñoz and Hubacek 2008; Wood et al. 2009; Weinzettel and Kovanda 2011). Efforts to offset increasing affluence through more sustainable production processes (technology effect) and consumption patterns (final demand mix effect) have so far not been sufficient to result in absolute decoupling. For most material categories, at least one of these two effects has increased material consumption even further (Fig. 1). While biomass seems to be the exception, it has to be noted that the observed absolute decoupling was mainly achieved between 1995 and 2000. If only changes between 2000 and 2007 were taken into account, biomass would show relative decoupling similar to other material categories.

Based on the findings of this study, efficiency gains would have to be much higher in order to offset the effect of economic growth and thus achieve absolute decreases in material consumption. However, the results for the time period between 2000 and 2005 provide interesting insights in this regard. This period was characterized by lower than usual annual GDP growth rates with an average of 1.7% as opposed to 3.4% from 1995 to 2000 and 3.8% from 2005 to 2007 (Statistik Austria 2013b). Not surprisingly, this affected consumption volume, which grew at a lower rate than during other periods (Fig. 6). While one would expect this to cause the rate of RMC growth to slow down, the opposite trend was observed. The rate of RMC increase was actually the largest during this time period. This was caused by the effects of more a material-intensive production technology and product mix. Regarding the mix effect, this indicates that consumers rather saved on those consumption activities with a lower

environmental impact (eg. services), while the consumption of material-intensive commodities kept rising steadily. This shift in consumption patterns during the second period (2000-2005) can be observed across all material categories (Fig. 2-5). It contributes to an increase in RMC for every material category except for non-metallic minerals, for which its decreasing effect at least was the lowest of all periods. In addition to the final demand mix, production technology contributed to a significant rise of the RMC of biomass during this period (Fig. 2). By comparison, it had a substantially decreasing effect in previous and subsequent years. This spike more than offset the opposing trend in production technology for non-metallic minerals (Fig. 4). Thus, the significant drop in efficiency of the production technology for biomass was the main reason for the increasing effect technology had on total RMC from 2000 to 2005.

This finding should not be misinterpreted in the sense that higher economic growth rates were better for the environment. The results show that, even in years of low economic growth, consumption volume is still the main driver of increases in RMC by far. However, these findings could support arguments brought forward by Van den Bergh (2010). He critically evaluates the concept of “degrowth” as a strategy to reduce environmental problems. One of his main arguments is that decreasing the scale of the economy (final demand volume) might not actually lead to environmental improvements, especially in the long run. He emphasizes the importance of the composition of production (technology effect) and consumption (final demand mix effect), which might be neglected when focusing solely on GDP degrowth. Instead, he recommends being indifferent about growth, thus aiming for “a-growth”, by focusing on the necessary environmental regulations and allowing GDP to adapt accordingly. This could probably lead to some sort of economic degrowth in the beginning though, so political and economic institutions should be prepared to deal with the consequences (Van den Bergh 2010). However, further research is needed to either support or invalidate the trend of an increasing material intensity during years of low economic growth, which was observed in this study. An SDA for the subsequent period covering the most recent economic crisis could provide insights into this matter, although the respective time period might still be too short to derive any trends.

Furthermore, a wider application of SDA to the RMC indicator, especially for those countries with high per capita consumption volumes, would allow for comparing the results obtained for Austria with countries in a similar economic situation.

## **Conclusion**

In this study I analyzed the underlying factors that drive Austrian raw material consumption (RMC). I further determined how these factors affected current decoupling trends of economic growth and material consumption for different time periods and material categories by applying a structural decomposition analysis.

The results show that improvements in the material efficiency of production and consumption were not able to compensate for increases in the scale of consumption activities, except for biomass. In order for decoupling to be a viable path to sustainable development, material efficiency of both production and consumption activities would have to increase at much higher rates than observed so far. For some material categories, production technology and consumption patterns even worsened the situation, thus increasing material consumption even further. This trend of increasing material intensity was mainly observed during periods of low economic growth, which supports the argument that, while economic degrowth might be a possible consequence, policies should focus on effective environmental regulations. These results further pose interesting opportunities for further research on the interrelation between economic growth and material intensity.

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## **Annex**

### **Methodological developments in decomposition analysis**

Decomposition Analysis is a comparative method to determine the underlying driving forces of a changing indicator. By disaggregating the indicator of interest into several factors, the contribution of each of these factors to indicator changes between two data-sets can be determined. Two different decomposition approaches have evolved independently and are therefore characterized by different mathematical models. Index decomposition analysis (IDA) uses aggregated sector or country level data and has mainly been applied to energy and emission indicators. Structural decomposition analysis (SDA) on the other hand uses input-output (IO) data. For a detailed comparison of IDA and SDA see Hoekstra and Van den Bergh (2003).

IDA is applied far more extensively than SDA, especially regarding environmental issues (Hoekstra and Van den Bergh 2002). Ang and Zhang (2000) published a review of IDA studies where they list and compare 124 IDA studies. A review of Hoekstra and Van den Bergh (2002) of SDA compared 27 studies. Su and Ang (2012) recently updated the work of Hoekstra and Van den Bergh (2002) by listing 43 SDA studies published since then. The difference in the frequency of application is mainly due to the fact that IDA requires less and generally easily available data. SDA uses data from IO tables and is therefore more data-intensive, but at the same time allows for a more detailed decomposition. With the use of the input-output approach and the application of the Leontief Inverse, indirect demand effects caused by inter-industry

exchanges of goods can only be captured by SDA (Hoekstra and Van den Bergh 2002; Miller and Blair 2009).

### **Decomposition methods**

Over the years, several decomposition methods were developed for both the IDA and SDA approach. These methods mainly differ in the index used to weight the different effects and can thus be divided into two groups, one linked to the Laspeyres index and one based on the Divisia index (Ang 2004). When indices such as the basic Laspeyres or the similar Paasche index are used, where one factor is changed over time while holding all other factors fixed, this is often referred to as ad hoc decomposition. These have been the most common decomposition methods in the 1970s and 1980s in both SDA (Su and Ang 2012) and IDA (Ang and Zhang 2000).

However, they suffer from serious shortcomings by failing both the factor-reversal test, which determines whether the decomposition is complete (also called perfect) or leaves a residual term, and the time-reversal test, i.e. results are affected in absolute terms when base year 0 and terminal year T are switched instead of differing only in sign (additive decomposition) or yielding reciprocal values (multiplicative decomposition), in index number theory (Ang 2004; Su and Ang 2012). Hence, an increasing number of studies in IDA were dealing with the development of more advanced indices that would overcome these shortcomings and at the same time were easy to use and interpret. Ang and Zhang (2000) and Ang (2004) give a good overview of these developments in IDA, where they describe a general trend towards methods based on the Divisia index instead of the Laspeyres index. In SDA, however, ad hoc decomposition methods kept being the most common choice until the late 1990s.

The D&L method introduced by Dietzenbacher and Los (1998) was then the first SDA method meeting the requirements of being (1) ideal (i.e. passing the factor-reversal test and not leaving any residual term) and (2) time-reversible (i.e. leading to reciprocal results if base and terminal year are switched). Around the same time the S/S method (Shapley 1953; Sun 1998), which is similar to D&L (Lenzen 2006; Su and Ang 2012), and the logarithmic mean Divisia index (LMDI) (Ang and Choi 1997; Ang et al. 1998; Ang and Liu 2001) were introduced in IDA, both of which pass the factor-reversal and time-reversal test as well. This study applies the LMDI method to an SDA setting. Thus, the following paragraphs will further elaborate on LMDI as a decomposition method and bring forward arguments for LMDI being a valid choice for SDA.

#### **Logarithmic mean Divisia index (LMDI)**

Unlike D&L and S/S, which belong to the Laspeyres family, LMDI is based on the Divisia index (Hoekstra and Van den Bergh 2003; Ang 2004). LMDI was first introduced by Ang and Liu (1997) and then further refined by Ang and Liu (2001). Ang and Liu (2001) refer to the former variant, introduced by Ang and Liu (1997), as LMDI II as opposed to the more refined LMDI I by Ang and Liu (2001) for consistency with the related Vartia indices I and II. In this study, as in most recent studies, LMDI refers to this more refined form (LMDI I). LMDI II is hardly used and Ang and Liu (2004) recommend applying LMDI I instead, mainly for its simpler formula. LMDI has since become one of the most common decomposition methods in IDA, mainly for its (1) solid theoretical foundation (i.e. passing the tests in index number theory, such as the factor-reversal test and the time-reversal test), (2) adaptability (i.e. it can be used for a variety of

decomposition problems), (3) ease of use (i.e. a relatively simple formulation) and (4) ease of result interpretation (i.e. easy conversion of results between additive and multiplicative form as well as no need to explain any residual terms) (Ang 2004).

The first attempt to transfer indices from IDA to the SDA setting was done by Hoekstra and Van den Bergh (2003)<sup>7</sup>. While in IDA both multiplicative and additive forms are used, this study follows the general SDA approach by applying the additive form. Unlike the multiplicative form, which yields relative changes, the additive form generates absolute changes (Hoekstra and Van den Bergh 2003; Su and Ang 2012).

### **Handling zero and negative values**

The main weakness of LMDI in an SDA setting has been its incapability to deal with negative and zero-values. This is caused by logarithmic terms used in the LMDI formulae which do not yield real numbers when applied to either negative or zero-values. However, these shortcomings have been overcome, thus making LMDI negative as well as zero-value robust.

Regarding zero-values, Ang and Choi (1997) solve this problem by replacing zero-values with very small values (around  $10^{-20}$ ) and Ang (2004) confirms that this small value strategy is the most favorable way to deal with zero-values. Wood and Lenzen (2006) point out though that this approach can cause significant errors when there are many zero-values in the data set, as it is typical for IOTs. They therefore recommend using the analytical limit approach instead when applying LMDI to SDA, which was first introduced by Ang et al. (1998) and then further refined by Ang and Liu (2007a).

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<sup>7</sup>Hoekstra and van den Bergh (2003) refer to the LMDI II approach as refined Divisia index.

Chung and Rhee (2001) criticize LMDI for its inability to handle negative values in the data set, as it is the case with changes in inventories. Hence, they present the mean rate-of-change index (MRCI) as the superior method. However, Lenzen (2006) shows that, while MRCI can handle negative values, the generated results are no more plausible than those produced by other decomposition methods. Furthermore, Ang and Liu (2007b) resolved LMDI's problems with negative values using the same analytical limit approach as for zero-values.

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## Anhang

### Zusammenfassung

Der weltweite stetig zunehmende Materialverbrauch steht in Widerspruch zu dem Konzept eines nachhaltigen Ressourcenmanagements. Sowohl in wissenschaftlichen als auch politischen Kreisen ist man sich mittlerweile einig, dass der Materialverbrauch zurückgehen muss. Dies gilt im Speziellen für Industrienationen, deren Materialverbrauch pro Einwohner deutlich über dem der restlichen Staaten liegt. Eine Senkung des Materialverbrauchs ist für Industrienationen wie Österreich daher auch unter dem Aspekt der globalen Verteilungsgerechtigkeit anzustreben.

Da ein stetiges Wirtschaftswachstum nach wie vor als politische Notwendigkeit angesehen wird, stellt sich die Frage ob und wie Materialverbrauch von Wirtschaftswachstum – und in Folge Konsum – entkoppelt werden kann. Bisherige Ergebnisse zeigen meist nur eine relative Entkopplung, bei der eine erhöhte



Materialeffizienz den in Folge einer wachsenden Wirtschaftsleistung zunehmenden Materialverbrauch zwar bremsen, aber nicht umkehren kann. Um eine absolute Entkopplung von Materialverbrauch und Wirtschaftswachstum zu ermöglichen, müsste daher die Materialeffizienz stärker zunehmen als die Wirtschaftsleistung (BIP).

Das Ziel dieser Studie ist es nun die zugrunde liegenden Einflussfaktoren hinter dem steigenden Materialverbrauch genauer zu untersuchen und deren jeweiligen Einfluss mithilfe einer structural decomposition analysis (SDA) zu quantifizieren. Als Indikator für den Materialverbrauch wird dabei der RMC (raw material consumption) herangezogen, ein Indikator aus dem Bereich der Materialflussanalyse (MFA), der im Gegensatz zu klassischen MFA-Indikatoren auch indirekte Materialflüsse im internationalen Handel berücksichtigt. Der RMC ermöglicht dadurch, die im Laufe des Produktionsprozesses verbrauchten Materialien und die damit verbundenen Auswirkungen auf die Umwelt jenem Land zuzuschreiben, in dem die gehandelten Güter letzten Endes verbraucht werden. Da es sich beim RMC um einen Konsumindikator handelt, wird zudem die für den Export bestimmte Produktion nicht berücksichtigt.

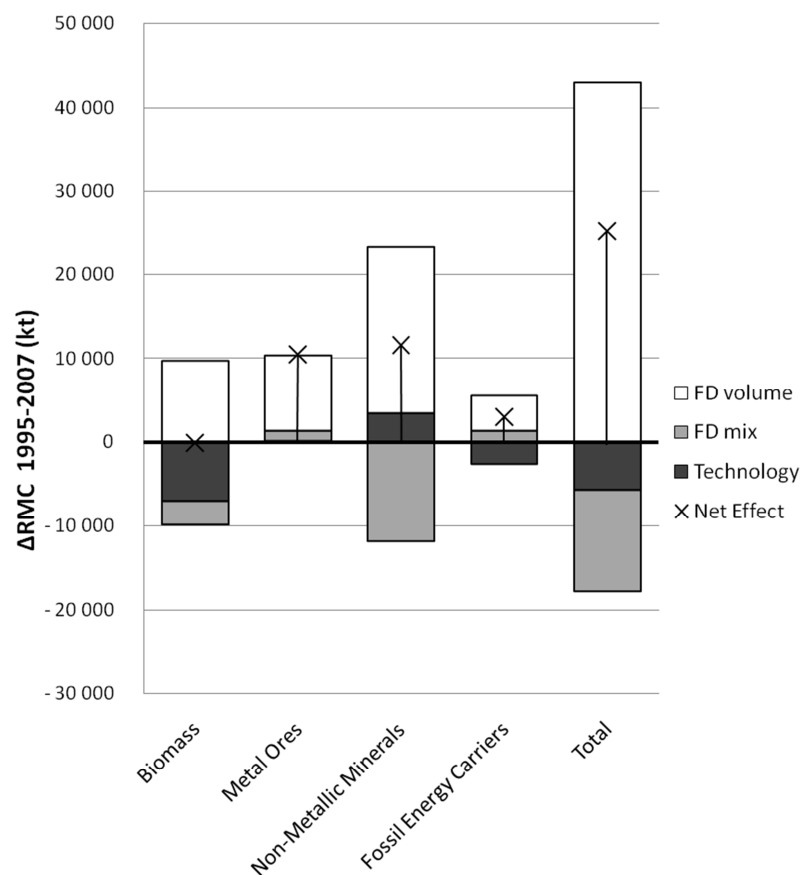
Die möglichen Einflussfaktoren, welche im Rahmen einer SDA untersucht werden können, sind im Grunde genommen durch die Faktoren im environmentally extended input-output (EEIO) Modell vorgegeben. Sie können aber in weitere Faktoren zerlegt oder auch kombiniert und so dem jeweiligen Forschungsschwerpunkt angepasst werden. Für diese Studie wurde der RMC in drei Faktoren unterteilt: Produktionstechnologie (technology effect), die Produktzusammensetzung des Endverbrauchs (final demand mix effect) und das Volumen des Endverbrauchs (final

demand volume effect). Der Faktor Produktionstechnologie stellt dabei den Materialverbrauch relativ zur wirtschaftlichen Leistung eines Sektors dar. Die Produktzusammensetzung spiegelt die Materialintensität der Konsumgewohnheiten einer Gesellschaft wieder. Sie zeigt wie sich der relative Mix konsumierter Güter und Dienstleistungen verändert und welche Auswirkungen das auf den Materialverbrauch hat. Das (monetäre) Volumen des Endverbrauchs bringt schließlich den Aspekt des Wirtschaftswachstums ein.

Eine SDA ermöglicht nun den Anteil jedes einzelnen Effekts an Änderungen des RMC zwischen zwei beliebigen Zeitpunkten zu berechnen. Der gesamte Untersuchungszeitraum zwischen 1995 und 2007 wurde in drei kürzere Abschnitte (1995-2000, 2000-2005, 2005-2007) unterteilt, um mögliche Unterschiede zwischen diesen Perioden mit unterschiedlichem Wirtschaftswachstum sichtbar zu machen. Desweiteren wurde jede der vier großen Materialkategorien (Biomasse, Metalle, nichtmetallische Mineralien sowie fossile Energieträger) separat untersucht. Die Daten dazu stammen von EEIO Tabellen, die von Schaffartzik et al. (2013) für Berechnungen des österreichischen RMC erstellt wurden.

Die Ergebnisse zeigen ein recht heterogenes Bild für die verschiedenen Materialkategorien (Figure 1). Wie erwartet führte das steigende Konsumniveau (final demand volume) für sich betrachtet zu einer Verbrauchszunahme aller Materialkategorien. Effizientere Produktionstechnologien (technology) konnten diesen Effekt für Biomasse und fossile Energieträger zumindest teilweise kompensieren. Im Fall von Metallen und nichtmetallischen Mineralien waren die Produktionsprozesse im Jahr 2007 allerdings ineffizienter als noch 1995. Veränderungen in der

Produktionstechnologie haben in diesen beiden Fällen also sogar zu einer weiteren Zunahme des Materialverbrauchs geführt. Änderungen der Konsumgewohnheiten und Produktzusammensetzung (final demand mix) konnten den Materialverbrauch im Fall von Biomasse und vor allem nichtmetallischen Mineralien erheblich reduzieren. Die relative Produktzusammensetzung des Konsums benötigt allerdings eine leicht höhere Menge an Metallen und fossilen Energieträgern.



**Figure 1** Decomposition of changes in raw material consumption (RMC) from 1995 to 2007 into the effects of final demand (FD) volume, final demand mix and technology in kt. The respective net effect is the sum of all three effects.

Die Summe dieser drei Effekte bildet den Nettoeffekt, der schließlich tatsächliche Änderungen im Materialverbrauch darstellt. In Verbindung mit den drei Einzeleffekten zeigt uns das, dass absolute Entkopplung von Materialverbrauch und Wirtschaftswachstum (beziehungsweise einem allgemeinen Konsumanstieg) nur für

Biomasse erreicht wurde, wobei man nicht wirklich von einer absoluten Reduktion sondern vielmehr von einer Stabilisierung des Biomasseverbrauchs sprechen kann. Nichtmetallische Mineralien und fossile Energieträger zeigen eine relative Entkopplung. Ressourcenschonende Technologien oder Konsumgewohnheiten konnten den Anstieg des Materialverbrauchs zwar bremsen, aber nicht aufhalten. Im Fall von Metallen konnte nicht einmal eine relative Entkopplung beobachtet werden. Hier wuchs der Verbrauch sogar noch schneller als der allgemeine Konsum. Durch Summierung der Ergebnisse der einzelnen Materialkategorien erhalten wir schließlich den gesamten Materialverbrauch. Hier zeigt sich, dass Veränderungen der Produktionstechnologie wie auch der Konsumgewohnheiten den Anstieg des Materialverbrauchs in Folge des Wirtschaftswachstums nur teilweise kompensieren konnten.

Die Studie zeigt zusätzlich, dass der gesamte Materialverbrauch zwischen 2000 und 2005 am stärksten gestiegen ist. Das ist deshalb überraschend, weil das Wirtschaftswachstum während dieser Periode im Vergleich zu den anderen Zeiträumen besonders niedrig war. Der starke Anstieg des Materialverbrauchs während dieses Zeitraums war daher durch ineffizientere Produktionstechnologien und einer materialintensiveren Produktzusammensetzung bedingt. Letztere deutet darauf hin, dass in Zeiten schwächeren Wirtschaftswachstums eher der Konsum von materialeffizienten Produkten und Dienstleistungen zurückgeht, während der Konsum materialintensiver Produkte weiterhin konstant zunimmt.

Zusammenfassend können wir feststellen, dass – mit Ausnahme der Biomasse – in Österreich keine Entkopplung von Wirtschaftswachstum und Materialverbrauch

beobachtet werden konnte. Um die aus Nachhaltigkeitssicht negativen Folgen des Wirtschaftswachstums zu kompensieren müssten die jährlichen Effizienzsteigerungen sowohl auf Produktions- als auch auf Konsumseite deutlich höher ausfallen als bisher. Dazu bedarf es allerdings strengerer gesetzlicher Regulierungen. Ergänzend muss die Notwendigkeit für Wirtschaftswachstum und die damit einhergehende ständige Ausweitung des Konsums hinterfragt werden.

## **Curriculum vitae**

### **Schule**

1989 – 1993	Volksschule Friesgasse, Wien
1993 – 2001	Matura mit gutem Erfolg am BG Rosasgasse, Wien

### **Studium**

2001 – 2002	Studium der Medizin an der Universität Wien
Seit 2002	Studium der Biologie an der Universität Wien, Studienzweig Ökologie mit Spezialisierung auf Humanökologie Wahlfächer am IFF Wien, sowie im Bereich der Umweltökonomie und Ökologischen Ökonomie an der Wirtschaftsuniversität Wien
2008 – 2009	1-jähriger Erasmus-Aufenthalt an der Vrije Universiteit Brussel, Belgien Department of Human Ecology

### **Arbeitserfahrung**

Sommer 2009	3-monatiges Praktikum bei SERI (Sustainable Europe Research Institute)
Sommer 2009	Mitarbeit und Moderationstätigkeit beim Projekt „WWViews – World Wide Views on Global Warming“ am Institut für Technikfolgenabschätzung (ITA)
2009 – 2010	Zivildienst beim WWF Österreich (Worldwide Fund for Nature)
2010 – 2012	Assistent in der Naturschutzabteilung des WWF Österreich