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Positive employment effects of increasing material efficiency

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Abstract

As raw and processed materials constitute a major share of the cost of inputs to industrial production in all developed countries and since the raw material crisis in 2009 revealed the criticality of the raw material supply worldwide, the increasingly efficient use of material resources has become an important point on the political agenda. One way to promote this increase is funding of research in efficiency-increasing technology innovations. Data describing the physical and economic effects of sixteen such innovations are used to model on the basis of input-output analysis the employment effect of these technologies once their full application potential in Germany would be exploited. It turns out that the employment effect is positive and its strong robustness is based on the combination of three promoting factors, each of which alone increases the likelihood of increasing employment. These factors refer to the profitability of efficiency-increasing technologies and to the import of foreign value added and the change in labour productivity characterizing many instances of material efficiency increase.

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1 Introduction

In Germany, raw and processed materials constitute forty percent of the cost of inputs to industrial production, while energy cost alone make up less than three percent. Nevertheless, for many years, the need and potential for an increase in use efficiency was mainly discussed for energy as this is thought to contribute significantly to the reduction of greenhouse gas emissions and, thus, to the protection of our climate. Only with the beginning of the third millennium, raw materials in general started to attract increasing attention as the supply of various resources turned out to become increasingly difficult from the physical and political perspective. This development culminated in the years 2007/2008, when extreme price increases on the raw material markets indicated an excess of demand over supply, and in 2009/2010, when China began to limit the foreign access to its raw material reserves by establishing export tariffs. Threatening fundamentally the basis for economic development in industrial countries and beyond, these crucial events forced policy makers and industry representatives in many countries to develop strategies for dealing with this challenge. The German Raw Materials Strategy (BMWi 2010) and the Raw Materials Initiative of the European Commission (EC 2008) are cases in point and both of them emphasize the increase in material use efficiency as one important strategy for ensuring long-term raw material supply.

Much earlier, in 2002, the German Government (2002) has already declared in its 'Sustainability strategy' its ambition to double by 2020 the raw material productivity1 assessed for the year 1994. By the end of 2012, 49 percent of this doubling has in fact been achieved (DeStatis 2014) and assuming the continuation of the current trend would lead to an efficiency increase by about 78 percent in 2020. This implies, however, that the gap to the goal of doubling efficiency will remain at 22 percent. In order to fill this gap, the main approach actually pursued by the German Government is subsidizing research and technology development towards higher efficiency. A case in point to this approach is the initiative 'Innovative Technologies for Resource Efficiency – Resource-Intensive Production Processes (r^2)' funded by the Federal Ministry of Education and Research (www.r-zwei-innovation.de), in which companies got the opportunity to improve the material efficiency of material-intense processes forming the core of their respective value-added chains. The projects constituting this initiative

1 The term raw material productivity is an indicator used in the official German sustainability monitoring (see DeStatis 2014), which refers to raw material use (in tons) per GDP (in Euro). It is a specific instance of the more general term resource efficiency.

provided very detailed data concerning the economic and ecological impact of the innovative processes under investigation. Additionally, the micro-level data were up-scaled to the level of the German economy, so as to enable a detailed analysis of the structural and macro-economic consequences of the technological advancements. To date the number of analyses of the (macro)economic impacts of an increase in material efficiency is rather limited. Meyer and his colleagues (e.g. Meyer et al. 2007; 2012) analyse and discuss the economic and ecological impact of applying different policy measures directed to increasing material efficiency. However, the measures investigated (e.g. information campaign or material input tax) are rather broad and so are the assumptions concerning the economic impulses. Accordingly, the results are somewhat unspecific. The same argument applies to the analytical approach of Di Vita (2007), who uses assumptions about the elasticity of substitution between primary and secondary material to deduct effects on the growth rate of the economy. Walz (2011), by contrast, uses a different approach modelling specific, efficiency-enhancing technologies, which enables him to draw more realistic conclusions. However, his study is limited to a narrow selection of industries covering only one part of the existing material efficiency potentials. The present paper adopts the modelling approach of Walz (2011) and expands its technological scope on the basis of a variety of different efficiency-enhancing technical innovations employed in six different material-intense industries. So, it is able to draw more realistic and, at the same time, more far-reaching conclusions regarding the economic effects of an increase in material efficiency.

The paper starts (in section 2) with a discussion of the methodological approach, describes the data used and explains how they are fed into the model. The results presented in section 3 show a strong correlation between increasing material efficiency and increasing employment. Various reasons for this are discussed in section 4 and the results concluded in section 5.

2 Materials and methods

2.1 Modelling approach

In order to assess empirically the economic effects of environmental policy, it is necessary to use empirical models quantifying the various links between different economic models. Basically three types of models are able to comply with this requirement – macroeconometric, computable general equilibrium (CGE) and input-output models – and each of them has its specific strengths and weaknesses (West 1995). For the analysis of the economic impacts of the implementation of innovative technologies increasing the efficiency of material use of in industrial production, Walz

(2011) uses an input-output model and provides the following argument supporting his choice. Especially in their static version, input-output models are not able to depict changes in demand brought about endogenously by income and accelerator effects. Additionally, they neglect substitution effects and the change in competitiveness caused by price and cost variations, unless these effects are included exogenously. Analyses with input-output models are therefore valid primarily in those cases, where a high degree of sectoral disaggregation is required and the analyzed measures can be assumed to have essentially no impact on the aggregated flow of income. Both criteria apply equally to the case examples analyzed by Walz (2011) and to those studied in this paper. In fact, unlike strategies for climate protection such as increasing energy prices by an eco-tax (which may be suitable for a good as homogeneous as energy), strategies to increasing material efficiency comprise a wide variety of different materials and are therefore discussed much more on the level of specific technologies. This implies a higher importance of structural impacts, which raises the need for a highly disaggregated model – a specific strength of input-output models. An advantage of CGE and macroeconometric models, on the other hand, is their representation of the government and its revenues and spendings. This feature is important, if a policy measure such as a tax is to be analyzed. By contrast, the implementation of the technologies analyzed in this paper is assumed to be economically self-sustaining and proceed without substantial intervention by the government. In this context, the funding provided for research into, and development of, the first facilities of each technology can be considered negligible compared to the investments needed for the economy-wide diffusion of the respective technologies, which will be the object of the present analysis. So, the input-output approach appears to be indeed suitable for the type of analysis to be conducted here.

The actual modelling of the consequences of the implementation of material efficiency-enhancing technologies is done by means of the Integrated Mesoeconomic Simulation System for Sustainability Assessment, ISIS, which is described more thoroughly in Walz et al. (2001). It consists of an input-output model with 71 productive sectors and 6 sectors of final demand, including private consumption, investment and exports. On the input side it distinguishes between intermediate inputs from other sectors, imports, labour and capital consumption (DeStatis 2007). Imports and labour are of special importance as they have immediate implications for employment in the respective sectors.

2.2 Data sources and usage

In order to elaborate the consequences of the implementation of efficiency-enhancing technologies, a scenario approach is used, in which the basic input-output matrix represents the reference scenario. This matrix is based on data from the German Federal Statistical Office (DeStatis 2010) representing the interdependence of sectors in the German economy of the year 2007.2 The employment of each of the efficiency-enhancing technologies represents a specific efficiency scenario, which can then be compared with the reference and with each other. Modelling of these scenarios is based on data input from 16 research and technology development projects funded by the German Federal Ministry of Education and Research in its initiative 'Innovative Technologies for Resource Efficiency – Resource-Intensive Production Processes (r^2)'. Each data set contains detailed data for one project concerning the realized changes of all material flows involved in physical and money terms, the necessary investments and their respective lifetimes (usually 15 years). The latter data and an assumed interest rate of 6 percent are used to break down the capital cost to annuities. Representing costs and revenues of single facilities, all data are then extrapolated to the total capacity that can potentially be installed in the whole of Germany. For this process of technology diffusion learning and scale effects of 15 percent (i.e. a 15% decrease in investment cost for each doubling of the cumulative installed capacity) are accounted for (Albrecht et al. 2012). This estimation is based on estimates of experts and the involved companies. Eventually, all savings and revenues (as calculated for the entire German economy) are respectively interpreted as negative or positive demand impulses and assigned to the respective supplying sector. Investments in the necessary technical facilities are assigned to the machine building industry, suppliers of process measuring and control technology and the construction sector with the respective shares being determined specifically for each technology. Applying these data as input to the ISIS model and comparing the results with the reference scenario yields data for changes in domestic production, gross value added, import values and employment not only for each technology (scenario), but additionally for each industry sector affected in every scenario. Table 1 lists the technical approaches to increasing material efficiency that were assessed and the clusters, to which they had to be aggregated in order to assure confidentiality to the involved companies.

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2 The data set for 2007, which is used in this study, is not the most actual one available. But it represents the last ‘typical’ year, which is essentially unaffected by the economic crisis and the resulting disturbances on the raw material markets. More importantly, the sectoral structure of the input-output matrix was changed since 2010 with such relevant sectors as 'production of secondary materials' not being represented specifically anymore.

Table 1: Technical approaches to improved material efficiency assessed in this paper and their aggregation to clusters

Cluster	Technical approach
Metal production	• Improved metal yields from copper slag • Phosphorus enrichment of converter slag for use as fertilizer • Thin-layer strip casting of HSD steels • Improved steel converter processing • More efficient electric-arc furnace • Resource-efficient shaping of titanium and heat-resistant alloys
Metal recycling	• Recycling fine-grained non-ferrous metal phases from shredder sand • Auto-thermal zero-waste metal recovery from WEEE scrap • Improved resource use in lead metallurgy • Extracting of the metal residues of mining waste dumps • Dezincification of steel scrap
Ceramics industry & construction materials	• Production of high-quality building aggregates from demolition waste • Controlled drying of ceramic products • More energy-efficient cement production
Chemical industry & coating processes	• Recovery of metal and process water in tin plate production • More efficient chlorine production

If assessed for the time frame of a wide diffusion of the respective technology in the economy, the balance between the savings from more efficient material use and the additional expenditures for machinery was found to yield a surplus, i.e. negative differential cost, in almost all cases. If, accordingly, processes are expected to be profitable, it is assumed that this will lead to an increase in either the wages or the profit in the respective companies, which will give rise to additional consumption or to further investment. In either case, this would lead to a general increase in demand, which is assumed to (positively) affect all industry and service sectors. If a process is not (yet) profitable, the same argument applies with opposite sign; so, all sectors would equally be affected negatively by the decrease in general consumption. The assignment of this general demand effect on the different sectors is based on their respective contribution to meeting the total demand in the reference scenario.

3 Results

3.1 Macro-economic effects

From the overview of the results provided in Table 2 it is evident at first sight that the contributions of the different clusters in terms of investment (and with respect to most other figures) are quite different and not correlated with the number of respectively assessed technologies. In the case of the ceramics and construction sector, for instance, this is not so much surprising, because the construction sector is in general very material intense and the investigated processes (i.e. the production of building aggregates and cement) are among the most important ones. By contrast, the chemical industry including coating processes exhibits the smallest contribution, which does not represent the relevance of this industry in the German economy, but its propensity to participate in the funding initiative.

Table 2: Macro-economic effects of the (German) economy-wide implementation of the material efficiency-enhancing processes described in Table 1

	Metal production	Metal recycling	Ceramics & construction materials	Chem. industry & coating processes	Sum
Investment cost, total (million €)	1,545.8	430.3	3,512.8	390.2	5,879
Differential cost, annual (million €)	-354.5	-160.9	-2,761.8	-71.9	-3,349
Ratio: total investment/ (negative) annual differential costs (years)	4.36	2.67	1.27	5.42	1.76
Domestic production, difference (million €)	-56.2	174.1	993.7	-59.0	1,044
Gross value-added, difference (million €)	102.1	103.0	539.1	-10.9	730
Imported production input, difference (m €)	-12.6	4.3	242.5	-11.0	222
Imports, total, difference (million €)	43.9	-96.0	508.4	8.3	463
People in paid work, difference, net	3,006	2,123	23,513	494	29,163
People in paid work, difference, total	7,215	3,103	59,421	1,566	71,305

Source: Calculations by the author

Altogether € 5.9 billion would have to be invested in the economy-wide installation of all material-efficient technologies listed in Table 1. At the same time, the differential costs for all clusters (and with one exception also for all technologies) are negative, implying that almost all investments will be profitable. In average, the investments can even be considered highly profitable, because the (negative) total annual differential cost exceeds one half of the investment indicating that the payback times are less than two years. They are even shorter (ca. 1.3 years) in the ceramics industry and construction materials cluster, while they slightly exceed 2.5 years in the metal recycling cluster, 4 years in the metal production cluster and 5 years in the chemical industry and coating processes cluster. However, these average values are of limited value, because especially in the metal production and metal recycling clusters, technology-specific payback times differ widely, ranging between one month and several decades or infinity, respectively.

With respect to domestic production, an increase in material efficiency is expected to have two effects. On the one hand, saved materials do not need to be produced and, accordingly, should lead to a reduction of production (= direct effect). On the other hand, the efficient use of materials leads to reduced expenditures with the saved money being spent for other goods, leading to an increase in production (= indirect effect). For the technical process innovations assessed in this paper, the cumulated domestic production increases by € 1.05 billion (see Table 2). This increase is caused by increases in only two clusters: metal recycling and ceramics industry and construction materials. In the other clusters, domestic production decreases slightly. In order to make sense of these differences, the changes in domestic production were respectively broken down into direct and indirect effects. As expected, the direct effects on domestic production turned out to be negative in all cases. Likewise, the indirect effects were found to be positive in all clusters. Only in the case of one technology (which is not decisive for the entire cluster) the indirect effect is negative (and the direct effect positive), because the more efficient use of materials does not give rise to money savings. Whether the combined effect is positive or negative eventually depends on the relative size of both effects. As can be expected on a logical basis, the profitability of the employed technologies is decisive for the indirect effect, because the more economical the innovative process is, the more money is saved and can be spent for other goods (giving rise to an increase in general demand). This proposition is well confirmed by our finding that the relative size of the indirect effect – specifically its excess over the direct effect (which is expressed by the change in domestic production in Table 2) – shows a good correlation with the ratio between (negative) differential cost and investment (see Table 2), which was interpreted above as a measure of profitability.

In order to avoid double counting, the gross value-added refers to the production values added (and not the sum of the total value of goods produced as in the case of domestic production) on each step of the value chain. It does so by subtracting the material input value from the respective production value. This should lead to gross value-added figures approximating slightly less than one half of the respective domestic production figures, which would reflect the average contribution of the (value of the) material input to the production value. This assumption is indeed found to apply for those two clusters – metal recycling and ceramics industry and construction materials – exhibiting positive domestic production, but not so for the other two (see Table 2). To explain the deviations, two factors have to be considered: the known distinction between direct and indirect effects and, for both of them, the share of material production input in domestic production. As discussed above, the indirect effects clearly exceed the direct effects in both, the metal recycling and the ceramics industry and construction materials cluster. As the indirect effects refer to general demand (referring to goods from all industries), it is not surprising that the total effect of material production inputs comes close to the average in both clusters. For the other two clusters, the indirect effects are not only smaller than the direct ones, but the share of production input value from total production value is larger than average for the chemical industry and coating processes cluster and much larger for the metal production cluster. Consequently, the (negative) gross value added is much smaller in the first case and even shows an opposite (i.e. positive) sign in the latter case.

The imported production inputs are an important indicator insofar as they determine the share of value-added imported from other countries. To the extent that value-added is imported, it does not contribute to domestic employment in the economy considered. As the imported production inputs are accounted for in the gross value-added figures, they do not exert an additional influence on employment. Instead, they convey an impression how imported inputs affect the gross value-added. As is evident from Table 2, the values of imported production inputs show the same signs as those of total production inputs in all clusters, as expected. However, the shares of the former as parts of the latter differ significantly. Like above, this outcome is due to the combined effect of direct and indirect effects on the one hand and the shares specific for those effects and the respective clusters on the other. Altogether, the impact of imported production input appears to be significant, but not decisive for the cases considered.

Imported production inputs are one part of total imports and, therefore, the latter affect employment even more strongly than the former. This is confirmed by the last column of Table 2. With respect to the clusters and the technological changes represented by them, total imports can be derived from production figures only to the extent that they contain imported production input as one part of it. The other part, final (consumer) demand, is exogenous to the model.

For the economic assessment of major technical changes, gains or losses of jobs are of special importance, because they are most strongly associated with the welfare of people. Remarkably, the implementation of material efficiency-increasing technologies leads to increases in employment in all clusters (see Table 2) and for all but one specific technology. Altogether the number of additional jobs is expected to increase by more than 29,000. Gross value-added and labor productivity are usually considered as being the decisive determinants for the changes in employment in the industries considered. Table 2 shows indeed a good correlation (r^2=0.74 on the cluster and r^2=0.98 on the technology level) between the gross value-added figures and the net changes in employment for most clusters. Only the cluster Chemical industry and coating processes shows a slight particularity insofar as the slightly negative gross value-added leads to a slight *increase* in employment. The decomposition analysis of direct and indirect demand impulses explains this outcome by the substitution of lower-wage for higher-wage labor. Jobs are lost in the chemical and related industries, which pay above average wages; and they are offset by the entire economy paying the average (by definition). Although it is evidently possible to explain the employment effects on the basis of gross value-added, closer inspection of Table 2 and the technology-specific data shows that, in this case, the differential costs are a much better determinant for the net changes in employment with the correlation being characterized by r^2 values of 0.9 and 0.999 on the cluster and technology level, respectively. Identifying the winners and losers in different sectors more specifically is the issue studied in the next subsection.

3.2 Structural effects

The employment effects resulting from the economy-wide implementation of material efficiency-enhancing technologies for specific sectors are presented in Figure 1. For the sake of clarity, all sectors with net changes of less than 200 jobs are pooled in 'Other sectors'. Negative effects are recorded for 13 of the original 71 sectors and for 9 of the 36 sectors specified in Figure 1. From the figure it is evident at first sight that the total changes (in either direction) are much larger than implied by the net changes. This impression is also supported by Table 2, which lists net and total differences in employment of 29163 and 71305, respectively.

With regard to the effects on specific sectors, prominent increases in employment are reported for the sectors 'Manufacture of building materials and ceramic products', 'Manufacture of machinery and equipment', 'Manufacture of instruments and appliances for measuring and controlling', 'Retail trade and repair of goods', 'Accommodation and food service activities', 'Public administration and defence', 'Education and support activities', and 'Human health and social work activities'. Evidently, the first sector listed takes advantage of the increase in demand for some of its products, which is manifested in the (large) cluster 'Ceramics industry and construction materials'. The direct employment effects of the other clusters are less

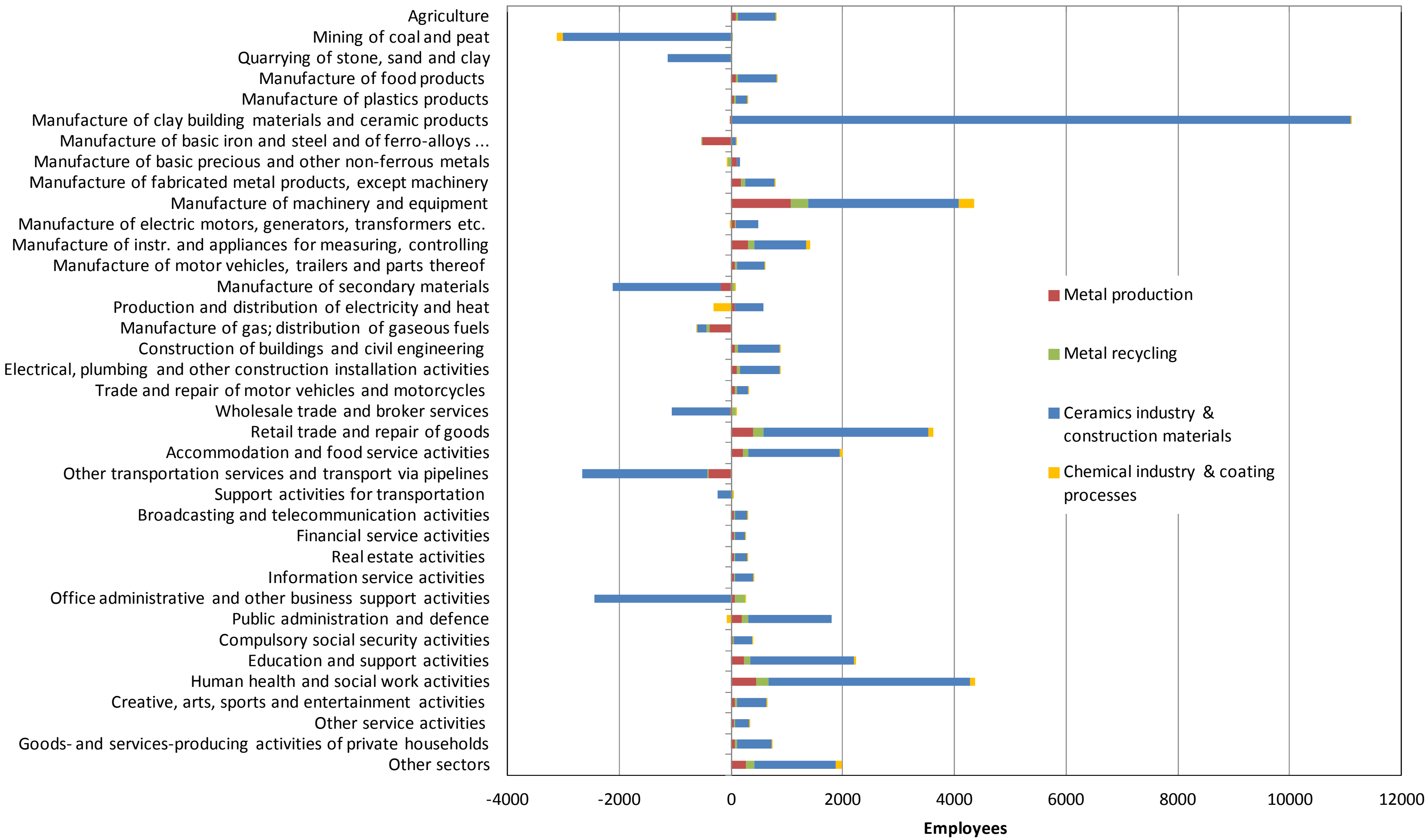

Figure 1 Employment changes in the sectors most affected by the (German) economy-wide implementation of the material efficiency-enhancing technical processes listed in Table 1 (Source: Calculations by the author)

easily identified, because not only the clusters are smaller, but additionally their demand for products of specific sectors is distributed more equally and over a larger number of sectors. The following two of the sectors listed, 'Manufacture of machinery and equipment' and 'Manufacture of instruments and appliances for measuring and controlling', represent the major part of the industries supplying the technological appliances needed for increasing material efficiency in all clusters. The remaining sectors, from 'Retail trade and repair of goods' to 'Human health and social work activities', comprise private and public service activities, which are not affected by the efficiency enhancement efforts directly, but indirectly through the general demand brought about by the additional income or profits caused by the efficiency, and thus productivity, increase.

The causes for a decrease in employment can also be grouped into different categories and assigned to specific sectors. However, the categories are different from those used above. The first category refers to the primarily affected sectors, i.e. those supplying the materials that are used more efficiently and, thus, in lower quantity. 'Mining of coal and peat' and 'Quarrying of stone, sand and clay' are evident cases in point, but also 'Manufacture of gas; distribution of gaseous fuels' and 'Manufacture of basic iron and steel' belong to this category (see Figure 1). The latter sector assumes quite different roles and in some cases even simultaneously: as manufacturer who uses other input materials more efficiently and as supplier whose products are used more efficiently. As a consequence, the aggregate (negative) employment effect is rather small, although the sector plays a central role in two clusters: 'Metal production' and 'Metal recycling'. Although recycling is part of the efficiency enhancing efforts investigated in this paper, even the 'Manufacture of secondary materials' is negatively affected, because output of this sector is used more efficiently (and in lower quantity) as input for the manufacture of construction material. The second category refers to service activities bought by the companies to manage their material flows; and because they succeeded in making their production process(es) more efficient, they need less of these services. This secondary employment effect is observed (in Figure 1) especially for the sectors 'Wholesale trade and broker services', 'Other transportation services and transport via pipelines' and 'Office administrative and other business support activities'.

4 Discussion

4.1 The effect of material productivity

In the previous section, one argument was found to mainly explain the positive effect of increasing material efficiency on employment: the increase in material productivity caused by the country-wide diffusion of material-efficient technologies, which gives rise to an increase in domestic production and gross value-added and, eventually, to an increase in employment. This argument is subject to two conditions: in order to lead to an increase in total productivity, the increase in material productivity must not be offset by decreases in the productivity of other factors such as labour and capital. This condition is met, if the innovative processes can be employed profitably (i.e. with negative differential costs), because this enables the production of the same output with less input. In this context, input means all types of inputs (incl. labour and capital) and both, inputs and outputs, are measured by their monetary values. However, meeting this condition is not sufficient.

With respect to demand, the efficiency increase, on the one hand, leads to a decrease in the use of, and demand for, *specific* input materials (saved by the innovative material-efficient technologies). On the other hand, the savings enable higher income, investment or tax payments, which will eventually give rise to an increase in *total* demand (expressed by consumers, firm owners or the government, respectively). This shift in the purchasing power strictly follows the circular structure of the economy modelled in the input-output approach and assumes crowding out of any additional demand impulses including, for instance, Keynesian effects such as additional investment under the condition of excess supply (Walz and Schleich 2009). Since this approach is rather conservative and does not tend to overestimate the positive effects of increasing material efficiency, the crucial question arises: How do the productivities of the production processes serving specific and total demand, respectively, relate to each other? If the general productivity is higher than the productivity of the sectors specifically affected by the efficiency-improvement, then any profitable and even slightly unprofitable, efficiency-increasing process innovation will give rise to an increase in domestic production. If, by contrast, the sectors negatively affected by the efficiency-improvement are more productive, only a higher profitability of these processes will ensure an increase in domestic production. For the material efficiency approach and the technologies assessed in this paper, this (first) argument including its qualifications is able to explain most of the employment effects of an economy-wide increase in material efficiency.

The economic 'mechanism' underlying the previous argument obviously also forms the basis for the larger part of the employment increase found by Meyer et al. (2012) in their study of the macroeconomic consequences of an increase in resource efficiency. In one of their scenarios, information instruments are used to inform entrepreneurs about potentials for increasing material efficiency in their companies. Using this approach, Meyer et al. assume that the material input cost of the manufacturing sectors could be reduced by 20%. The cost of implementing this approach and realizing these savings is estimated to show a payback time of one year. Both assumptions are significantly more optimistic than suggested by the results presented in this paper, where the average payback time is 1.76 years and the achieved material input reduction only 3.4% (Ostertag et al. 2013). From the latter figures, it can reasonably be assumed that the specific cost of a reduction by 20% would in fact be much higher, giving rise to even longer payback times. Irrespective of this difference, however, the modelling results of Meyer et al. (2012) suggest that referring extensively to the low-hanging fruits of increasing material efficiency indeed gives rise to strong increases in gross domestic product (GDP) and employment (by 14.2% and 1.9%, respectively, in 2030). Does this imply that the positive macro-economic consequences of an increase in material efficiency strictly depend on the profitability (i.e. negative differential cost) of the employed innovative processes?

4.2 The effect of imports

Knopf et al. (2013) answer this question in their assessment of the macro-economic impact of the implementation of an extended quota for the recycling of iron and steel, non-ferrous metals and mineral construction material. Since they assume the recycling of these materials to play a decisive role in reaching the goal of the German government of doubling material productivity by 2020, they assume a rather strong increase in the recycling quota of the aforementioned materials by around 20 percentage points. As this target is rather ambitious, they further assume that the differential costs of the necessary technical measures are positive, with the costs exceeding the revenues by about 30% (average percentage for the time period from 2012 to 2020 and for the different materials considered). Despite these positive differential costs, the macro-economic effects are positive or, at least, not clearly negative. As is shown in Table 3, domestic production and gross value-added clearly increase for the recycling of non-ferrous metals and mineral construction, while the case of iron and steel is more complicated. If, like in the case of non-ferrous metals, iron and steel scrap were collected mainly in Germany, domestic production and gross value-added would also increase in this case, because formerly imported raw materials are produced inland and, accordingly, the related (foreign) value-added is 'imported'. This argument is supported by Meyer et al. (2007) and Walz (2011). Additionally, in reverse application of the constant purchasing power argument raised in section 4.1, the positive differential costs displace total demand and the imports satifying it. The import figures shown in Table 3 support both arguments. In this case, it is also not surprising that the employment increases significantly.

Table 3: Macro-economic effects of the (German) economy-wide implementation of far-reaching recycling quota

Raw material	Differential cost, annual (million €)	Domestic production, difference (million €)	Gross value-added difference (million €)	Imports total, difference (million €)	People in paid work, difference, net
Iron/steel (including 'remport' of 80% of the needed scrap)	1,170	-4,243	-1,028	1,036	-14,151
Non-ferrous metals	1,304	3,300	1,605	-1,812	23,947
Mineral construction material (gravel and sand)	168	223	102	-97	5,132
Sum	2,642	-720	679	-873	14,928
Iron/steel with no scrap import	1,170	760	716	-877	12,773

Source: Calculations by the author in Knopf et al. (2013)

In fact, however, the scrap available in Germany is re-used almost completely already today. If the recycling quota is to be extended as assumed above, 80% of the additionally needed scrap has to be (re)imported (WV-Stahl 2010). In this case, domestic production and gross value-added become clearly negative and so does the number of employed people. So, beside the possible profitability of increasing material efficiency, the import of foreign value-added can be a second important argument in favour of an increase in employment owing to a more efficient (primary) material use. This argument is also supported by the outcome of a scenario assessed by Meyer et al. (2012): when the increase in material efficiency is enforced by a compulsory recycling quota, the increase in domestic production is much smaller than in the information-based scenario (described above), which is to some extent due to a smaller part of the economy being affected. If this size effect is accounted for, however, the number of employed people increases much more than domestic production.

4.3 The effect of labour productivity

Eventually, a third argument in favour of the positive employment effect of increasing material efficiency refers to the differences of the productivity of labour and, accordingly, the wages paid in the sectors affected by the efficiency improvement. In the sectors 'Manufacture of basic iron and steel' and 'Manufacture of non-ferrous metals', for instance, the value-added per working person is significantly higher (€ 140,000) than, or almost equal (€ 86,400), respectively, to the average of all manufacturing sectors of the German economy (€ 82,600). By contrast, the corresponding figure for the sector 'Manufacture of secondary materials' is only €

71,700. This implies that if the demand for primary iron and steel were replaced by the demand for scrap, also a low or even slightly negative increase in value-added could give rise to a substantial increase in employment, because the lower productivity would give rise to lower wages and, accordingly, the same value added would allow for, and require, a larger number of people being employed. In order to test the validity of this proposition, the sector-specific positive and negative changes in demand were separated and the labour productivity determined as gross value-added per employed person for the technology clusters investigated in section 3. The results, which also include mutual supply relationships specified in the input-output table and the increase in total demand caused by the negative cost differentials, are summarized in Table 4. They evidently support the employment-increasing effect of the decrease in labour productivity caused by the increase in material efficiency. Basically the same effect brought about higher employment in the cases studied by Knopf et al. (2013) and listed in Table 3.

Table 4: Labour productivity characterizing the positive and negative sector-specific demand changes caused by the employment of material efficiency-increasing technologies

Labour productivity (in € value-added per employed person) arising from …	Metal production	Metal recycling	Ceramics & construction materials	Chem. industry & coating processes
… positive changes in demand	64,242	57,863	64,455	60,391
… negative changes in demand	81,530	72,462	66,891	95,760

Source: Calculations by the author

In this context, it should be noted, however, that the lower productivity in the sectors benefitting from increasing material efficiency may not last forever. At the moment, a large share of the activities in these sectors comprises the collection and separation of waste yielding secondary raw materials, which is indeed less qualified, lower wage work. In the future, by contrast, after the low hanging fruits are harvested, the recycling of materials may become increasingly difficult. As a consequence, the qualifications required by the workers and, thus, their wages may increase.

5 Conclusion

It could be shown in this and several other studies (e.g. Meyer et al. 2012, Walz 2011) that an increase in material efficiency can induce positive employment effects. In this study, an input-output model was used to distinguish and identify the contribution of specific efficiency-increasing technologies and the economic sectors affected by them to the respective changes in employment. It turned out that the increase in employment caused by the increase in material efficiency is a quite robust effect and this robustness is in fact based on the combination of three cumulative effects.

First, the increase in material efficiency itself exerts two effects: the direct effect of lesser input material being produced and lesser workers employed and the indirect effect that the saved money is spent elsewhere in the economy, which leads to more demand and higher employment. Which of both effects, direct or indirect, prevails depends mostly on the profitability of the respective efficiency-increasing technologies deployed. If the costs of deploying them is exceeded by the respective revenues – i.e. they are operated profitably – the indirect effect tends to be stronger than the direct one and, consequently, employment tends to increase.

The second important factor is the origin of the used resources. Recycling of used materials, for instance, is an important aspect of increasing use efficiency to the extent that primary production inputs are replaced by secondary ones. In this context, it has to be noted that in Germany the main part of the primary raw materials is imported while secondary raw materials are the output of recycling processes, which mainly carried out inland. With regard to employment, this implies that the demand for secondary materials rests on production capacities and the respective working force inland, whereas the demand for primary materials is satisfied by production facilities and working people abroad. So, the use of a higher proportion of secondary (raw) materials will *ceteris paribus* lead to a higher value added and, thus, employment in Germany.

Eventually, the third employment factor is the change in labour productivity. Through the increase in relevance of material efficiency in general and recycling in particular some economic sectors win while others lose. Actually, some of the expanding sectors exhibit a lower labour productivity than those with decreasing capacity and employment. This means that employment in terms of employed people can increase despite a decrease in produced value-added and income, simply because the additionally employed people are (in average) paid less than those losing their jobs. This effect is actually observed, but it cannot be taken for granted in the long term, because the productivity may increase once the now less productive sectors become technically more highly developed. For the moment, however, this effect indeed contributes to the positive employment effect of increasing material efficiency.

In the context of an increase in material efficiency, each of those three factors alone is likely to lead to an increase in employment and their effects are cumulative. Conversely, none of the factors is likely to bring about negative employment effects and, if it did, the negative effect would probably be offset by one or both of the other factors. Therefore the combined positive effect of all three factors is quite robust.

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