Resource Efficiency Potentials of Manufacturing Industries

A comparison of resource saving potentials of single companies vs manufacturing value chains

Summary Paper

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Content

1 Executive Summary

This study analyses potential ways to increase the resource efficiency of manufacturing companies, which is one of the key challenges that this industry is facing today. The resource efficiency of a manufacturing company or process is the relationship between product output and resource input. The term 'resource' encompasses raw materials, energy resources and all operating supplies required for value generation.

The majority of measures and approaches currently applied to optimise resource efficiency focus on factory level actions and are often limited to single manufacturing processes or single resources, such as energy use. A wider and integrated optimisation strategy is assumed to have the potential for significantly higher resource saving. It is assumed that such a strategy should include, in particular, the integrated optimisation of all relevant energy and material resources used in the manufacturing of a product; across the interfaces between different steps in complex industrial value chains[1]; and between different companies involved in production. The term 'manufacturing value chain' is used in the study to address those steps of the overall supply chain that are dealing with the production of discrete parts, components and final products (as distinguished from process industries).

This study has two main aims;

(i) The evaluation of company level resource efficiency saving potentials;

(ii) The evaluation of the resource saving potentials of two exemplary manufacturing value chains;

which are briefly explained in the following.

(i) The evaluation of company level resource efficiency saving potential

The study set out to develop a better understanding of the resource saving potential of measures taken within single companies. This has been undertaken through an analysis of 100 recent case studies of single-company optimisation under the German Materials Efficiency Programme. This found that an average annual raw material saving of 7% and total resource saving (including energy, supplies etc.) of about 10 % had been achieved in relation to resources used in production by the companies analysed. The related total annual cost saving (i.e. for saved materials, energy, water, waste, and other supplies) typically exceeded one-off investment costs required to implement these saving. Consequently payback of investments could be achieved in less than 1 year; with average payback times increasing with company size from an average of 8 months for the smallest companies (those with a turnover of less than 2 m€) to 11 months for the largest companies (those with a turnover over 50 m€).

Directly comparable UK data on materials consumption of manufacturing SMEs is not currently available. However, a subset of the ENWORKS Efficiency Toolkit[2] dataset has been utilised with a sample of 90 companies from industry sectors that are broadly comparable to those featured in the German analysis. While a comparison of resource saving related to

[1] Wikipedia: „An industry value chain is a physical representation of the various processes that are involved in producing goods (and services), starting with raw materials and ending with the delivered product (also known as the supply chain)"

resource consumption before optimisation was not feasible, data on the average annual material saving achieved and the associated average investment required to realize the saving was available. The analysis found the average return on investment was less than 3 months for SMEs, against 8 months for large companies in the UK sample. Hence, the profitability of the measures implemented in the UK seems to be even higher than in Germany.

For a wider European perspective, results from a self-assessment of resource efficiency performance of 308 European SMEs have been analysed. Although this also includes subjective data, the results could help to understand better what company managers see as the most critical gaps in resource efficiency performance. One particular aspect that came out of this analysis is the important impact of worker skills on resource efficient manufacturing.

(ii) The evaluation of the resource saving potential of two exemplary manufacturing value chains

The study sought to test the assumption that the optimisation of value chain interfaces could have even higher potential for resource saving than mere company level improvement. Until now, little knowledge has been available about the actual saving potential of such approaches. As a pilot the study therefore modelled the resource inputs and outputs (energy, raw materials and supplies) of two, exemplary real-life manufacturing value chains using life cycle simulation. The selected examples were a typical metal mechanical production value chain and a typical value chain from mass production of plastics components. The modelling was performed with support from industrial companies that are part of the selected value chains.

The results of these simulations showed very substantial resource saving potential of 55% and 70% when comparing best case and conventional case scenarios, hence an order of magnitude higher than the saving potential of single company optimisation measures. In particular, in the case of metal mechanical production (55% saving potential) this result is almost exclusively related to improving interfaces of the value chain without major changes of the individual production processes. In the case of plastic processing (70% saving potential) substantial re-engineering of the entire value chain would be involved. Hence, real-life implementation of the latter case would require substantial investments.

Even though these findings are based on only two exemplar results, discussion shows that these results positively support the assumption of substantial saving potentials from the optimisation of value chain interfaces. This could be a 'next wave of eco-innovation' with a very high leverage effect.

Caveats and assumptions

With regard to the overall validity of data provided in this study the following aspect should be noted:

All data are related exclusively to manufacturing industries with a focus on sectors such as fabricated metal products, mechanical engineering, plastic products and chemicals. One

[2] ENWORKS online Efficiency Toolkit http://www.enworks.com/our-support/toolkit

exception is the sample of the self-assessment which has a broader sector focus; the limitation of this analysis due to subjectivity of data has already been mentioned. Concerning the datasets from company level resource efficiency programmes in Germany and the UK, these have been generated in both cases by various consultants supporting the companies in the implementation of measures. While this approach has its merits it could increase the uncertainty of data due to different approaches used in the analysis of the saving potentials.

With regard to the pilot approach to study value chain optimisation potential the major concern is that these two examples do not allow for the generalisation of the results achieved. Nevertheless, the selected examples are two typical cases of the concerned sectors and as such have at least a representative character.

Conclusions

A strong interrelation of the use of materials and energy in manufacturing processes and the related saving potentials has been found. This seems to be clearly pointing to the fact that a separation of measures for energy efficiency and raw materials efficiency would be suboptimal compared to approaches pursuing an integrated resource efficiency optimisation strategy. This is equally valid for the definition of according policy programmes.

The potential of industrial value chain (or supply chain) optimisation is not well used by companies; hence a significant saving potential is still being neglected. This has been well demonstrated by the analysis of two exemplary manufacturing value chains. **Both value chain simulations have shown resource saving potentials which are by a factor 5 higher than those of single factory improvements.**

With regard to policy recommendations, most important is a better understanding of resource efficiency potential and in particular, to understand that the four dimensions to 'resources' – i.e. raw materials, energy, supplies and wastes – are equally important, that they are strongly interlinked across the value chain of a product, and require integrated optimisation to get optimal results.

2 Introduction

Sustainable use of resources has been on the political agenda for over 30 years now, with environmental policies and instruments focusing primarily on compliance with regard to emissions, energy efficiency and the reduction of waste and wastewater. Today, it can be said that industrial companies have well responded to this challenge: emissions limitations are respected, and the use of resources per European inhabitant has practically been stable since the nineteen-eighties whilst in the same time the economy has grown by 50%.

Like many industrial technology fields, eco-efficiency is developing waves: In the past, industry and policy have relied mainly on so-called 'end-of-pipe' measures, such as cleaning wastewater and air, and recycling. Continuous improvements in energy efficiency came up with the first oil crisis, while material optimisation has still focused on product functionality and less on resource use. Today, this approach is not sufficient anymore if Europe wants to ensure a sustainable future for its manufacturing industry.

Hence, over the last ten years, increasing attention has been paid to the potential depletion of abiotic resources and the rising costs of raw materials. R&D efforts have been targeted on this area for more than a decade and programmes and initiatives to improve material efficiency of industrial companies (similar to the energy efficiency programs of the 1990's) have emerged throughout Europe, with a prominent example of the German Materials Efficiency Programme with over 600 completed cases.

In this context **the present study is arguing for a 'Next wave of eco-innovation', addressing resource efficiency optimisation of whole manufacturing value chains** instead of isolated single company / single process optimisations and, looking at resource efficiency with a holistic view that includes energy, raw materials as well as other supplies in an integrated optimisation approach. This will be discussed hereafter by reviewing the study results achieved. More detailed information is available in the Technical study document.

Study background

Far ahead of personnel costs (at 20%), **raw materials represent the largest cost share** for manufacturing companies at 35-40% of total expenditure, followed by energy costs at 10-15% (Fig.1). Thus, materials and energy are by far the most critical cost factors for a manufacturing company; its competitiveness in the global context will be determined by its capacity to use resources efficiently.

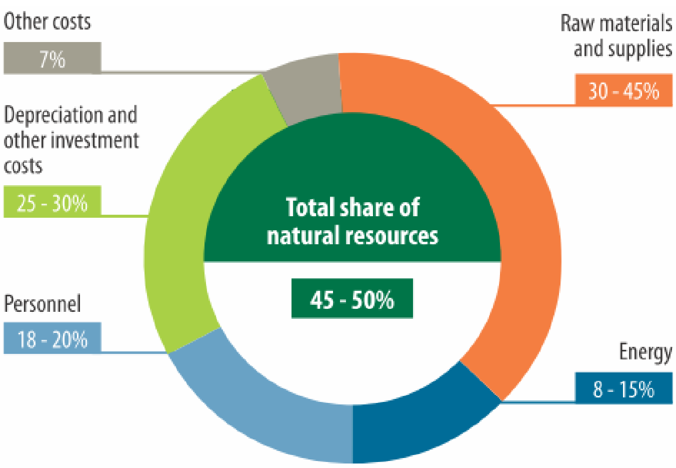

Fig. 1: Average shares of natural resources (materials and energy) in total manufacturing costs (Greenovate! Europe 2012)

As shown in Fig. 2 for Germany, labour productivity has increased since 1960 much more than material and energy productivity[3]. With variations the same is also true for most European countries. Analysis

[3] Statistisches Bundesamt (2008); H. Rohn et. al. (2008)

also shows a clear impact of resource productivity on European competitiveness.[4] By using fewer resources and optimising their use, businesses become more environmentally friendly, competitive and profitable. A substantial increase in resource efficiency is essential to achieve sustainable green growth. It is also economically sensible; with current inefficient use of resources calculated to cost European manufacturing industry around € 100 billion per annum.[5]

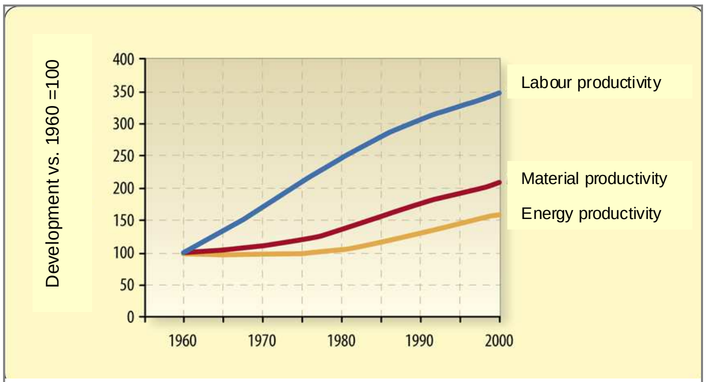

Fig.2: Development of labour, material and energy productivity in Germany, 1960–2000 (German Federal Statistical Office (2008); H. Rohn et. al. (2008))

Objective

The most important question in this context is how these saving could actually be realised. **Present approaches to resource efficiency are mainly focused on improving single manufacturing companies** and often only single sources (namely energy). The saving from such shop floor measures observed at single companies is typically in the order of 10% of the firms' resource consumption. This is the potential that can easily be tapped by applying Best Available Technologies.

The assumption of the present study is that even higher saving potentials could be addressed by optimising entire manufacturing value chains. So far, the resource efficiency potential of value chain optimisation has only been analysed at macro-level across some industrial sectors.[6] In contrast, this study is seeking to understand this saving potential by modelling two real-life production value chains typical of the manufacturing industries with a so-called life cycle simulation. Even though this could only be a first pilot approach, this could provide relevant indications for future initiatives on resource efficiency improvement.

Methodology

Companies adopt a variety of strategies, business practices and measures to increase their resource efficiency. Nature and intensity of the measures chosen may vary by business sector according to different priority areas for resource saving. Nevertheless, there are three principal approaches to improve resource efficiency:

- Improving resource efficiency of manufacturing processes at factory level;
- Integrated resource efficient process optimisation of across the entire industrial value chain;
- Eco-efficient product (re-)design.

The first two measures are the objective of this study. Since both approaches are addressing manufacturing optimisation, they are relevant for any company and particularly SMEs, while not all companies have end-use products for which product design is relevant. Moreover, the

4 R. Bleischwitz et. al. (2009)
5 Greenovate! Europe, REMake Project (2012)
6 R. Baron, et. al. (2005); Bayerisches Landesamt für Umwelt (2009); R. Erhardt, N. Pastewski (2010); K. Kristof, P. Hennicke et. al (2010)

potential of sustainable product design has already been analysed in various studies. The main characteristics and definitions of these two approaches are explained below.

Factory level improvement of manufacturing efficiency:

> Manufacturing processes transform raw materials and other inputs into finished products. The resource efficiency of a manufacturing company or a single manufacturing process is the relation of product output to resource input. It characterises how efficiently resources are used to generate economic value added. Relatively small changes to the manufacturing process can have a large impact on resource use. Identifying 'low hanging fruit' – low cost measures that can reduce both the environmental impacts and costs of manufacturing – is hence a win-win situation.

The 'next wave' - integrated optimisation across the manufacturing value chain:

> Improving the resource efficiency of manufacturing is usually only undertaken at the level of single factories or single processes, leaving room for further improvement **in particular at the interfaces between such processes and factories**. One company's output is another company's input, requiring cooperation and communication to achieve efficiency gains. From obtaining natural resources to a final product being sold, there are many steps to be coordinated to ensure the efficiency of resource use. If inputs do not meet exact output specifications, then large quantities of resources are wasted.
>
> Moreover, improving one single process in a manufacturing value chain does not necessarily imply an improvement of the overall life cycle efficiency of a product. For instance, if a reduction of material or energy consumption could be achieved by using a new material while at the same time recyclability at the end of life is worsened due to the new material's properties, the overall resource efficiency across the life cycle could be decreased. On the other hand, it could be appropriate to build an end-product on a semi-finished product requiring a more resource intensive production if this increases the overall product life time.
>
> Hence, to improve the resource efficiency of manufacturing industries more substantially requires far-reaching optimisation across the full manufacturing value chain, and a re-thinking and re-design of manufacturing networks towards more closely integrated supply chains. Addressing the overall manufacturing value chain in such an integrated way should lead to substantial advances in overall process efficiency and sustainability.[7]

The definition of an 'industrial value chain used in this study' is „… a physical representation of the various processes that are involved in producing goods (and services), starting with raw materials and ending with the delivered product (also known as the supply chain)"[8] The term 'manufacturing value chain', in particular, is used in the study to address those steps of the overall supply chain that are dealing with the production of discrete parts, components and final products (as distinguished from process industries, compare Fig. 3[9]).

Due to the complexity involved there are very few companies who manage their whole value chain in this way. As a consequence, little concrete information on actual saving potentials of typical manufacturing value chains is available which could motivate companies to invest in such optimisation strategies. The study therefore intended to contribute to overcoming this problem by providing more reliable estimations of saving potentials from typical, real-life value chains of the manufacturing industries, in comparison to single factory optimisation.

[7] compare also H. Walbaum, N. Kummer (2006); R. Neugebauer, D. López (2009)
[8] http://en.wikipedia.org/wiki/Value_chain
[9] Fig. 3 demonstrates also the relevance of this sector in Europe (data relate to EU27)

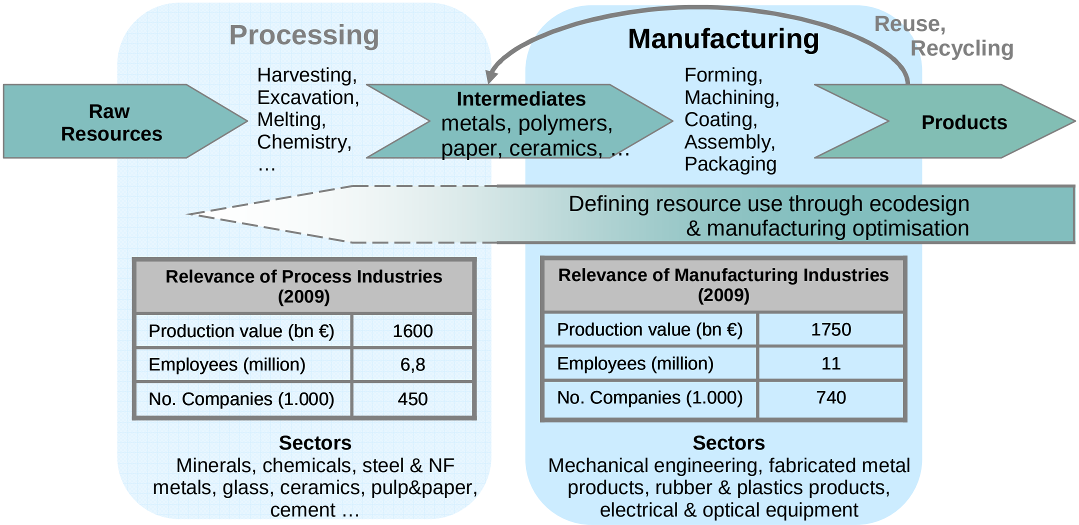

Fig. 3: Industrial value chains of processing vs manufacturing industries

Sources:
- Modified version of the value chain model used by the Royal Academy of Engineering (UK), in: „Industrial Systems: capturing value through manufacturing“ (2012);
- Eurostat Data on production values of key manufacturing sectors;
- Cefic, EUnited et. al. 2011 „Proposal of a Sustainable Process Industries‘ PPP“ on process industry data

The following approach has been implemented:

1. Analysis of typical saving potentials at the level of single factories

- As a basis, a sample of 100 German case studies on resource efficiency optimisation has been statistically analysed[10]. The case studies had been performed under the German Material Efficiency Programme, with a focus on the metal mechanical and plastics processing industry sectors.
- A similar sample of statistical data on materials consumption of manufacturing SMEs in the UK has been analysed based on data from the Enworks database.
- In order to integrate also a wider European perspective, results from a self-assessment implemented under the REMake project with company data from 5 EU member states (DE, ES, FR, IT, UK) have been included. The sample covers 308 self-assessment questionnaires completed by SMEs addressing their own perception of resource efficiency performance.

2. Quantitative modelling of resource saving potentials oft 2 manufacturing value chains

- In a pre-study, manufacturing chains from three industry sectors have been identified as typical examples for an in-depth analysis.
- Two of these production chains have been modelled with a life-cycle simulation software using materials and energy flow data as well as related product output from two manufacturing companies overseeing the whole value chain. Both companies had agreed to provide all the data required (including upstream supply chain data) under the condition that they received the analysis results free of charge and that the case studies are kept anonymous in this report.

  The saving potentials of best available technologies, processes and business practices of different stages of the production chain have been simulated and compared to the current state. Data on best available technologies and procedures have been taken from literature, data bases and IPPC BREF documents as well as from discussion with experts of the companies involved.

3. Comparison between factory level and value chain level saving potentials in order to draw conclusions on future priorities in designing resource efficiency strategies and initiatives.

[10] According to the German data protection law all company data had to be made anonymous so that no conclusion on the actual company concerned is possible.

3 Company level resource saving potentials

The German experience

The German Materials Efficiency Programme[11] has been supporting over 600 efficiency improvement projects since 2006. As a basis of this study, a sample of 100 case studies from the programme has been selected from resource efficiency projects performed during 2010 to December 2011. The sector focus was on metal mechanical and plastics processing industries as well as automotive and mechanical and electrical engineering.

The following types of data are included in the analysis:

1) Company data such as industry sector, number of employees, annual turnover etc.[12]
2) Economic data on resource use and saving potentials identified:
   - Materials and energy input
   - Other resource inputs
   - Resource saving including material savings and other savings such as energy, labour costs and other cost savings, where available.

   Savings are mainly given in monetary units since physical units from different materials were difficult to compare and were not always available.
3) Types of measures selected to improve resource efficiency and the impacts achieved.
4) Investments required to implement these measures, both one-off and yearly investments.

All data is related to one production year; and the following **definitions** are always valid:

- Turnover means annual turnover;
- Material, energy or other resource savings mean annual savings of these resources
- Resource inputs mean annual inputs of the according resources

Resource saving in relation to industry sectors and company sizes

All case studies fell in one of the following industry branches:

- Metal processing: steel production, foundry, sheet metal forming, metal construction etc.
- Machine / automotive / electrical industry: This category summarises data from automotive and other vehicle producing sectors, including suppliers, machine construction as well as electrical industry and engineering.
- Other sectors: This includes a variety of companies in particular from plastics manufacturing, environmental engineering, chemistry etc.

Table1 gives an overview on the number of companies and average company size (turnover) in each sector category as well as the average material saving potentials and the investments required to achieve this. Average ‘1st year investment’

Sector	Av. annual material saving in €	Av. 1st -year investment in €	Average turnover in k€	Average number of employees	Number of companies
Metal processing	164,366	170,248	19,221	127	58
Mechanical eng.; automotive; electrical industry	165,881	166,137	27,433	162	27
Other sectors	385,021	518,002	67,637	270	15
All 100 companies	**197,873**	**227,047**	**27,906**	**157**	**100**

Tab. 1: Average annual material savings; investments;company size per sector

[11] In August 2011 this has been integrated to the Innovation Voucher programme as one module named ‘go-effizient;’ http://www.demea.de/foerderung/go-effizient

[12] Of course, according to the German data protection law company data have been made anonymous so that no conclusion on the actual company concerned is possible.

means one-off investment for implementation of the measure plus the amount of eventually required annual investments in the 1st year.

The **metal processing sector** is represented by 58 companies which have on average 127 employees and an average turnover of about 19 m€ per year. Companies of the **'Mech. eng. /automotive /electrical industry'** category have a higher average turnover of 27 m€, and approx. 30% more employees (i.e. 162 on average). Though differing by size, **average annual material savings and investments** are similar for the two sector categories:

- Metal processing companies save on average 164 k€ at a first year investment of 170 k€ (i.e. saving represents 97% of investment). Accordingly the investment will be paid back in little more than one year on average.
- For the sample of the 'Mechanical engineering / automotive / electrical industry', the values are quite similar though companies are larger: Material saving is approx. 166 k€ for an average investment of 166 k€ (saving equals 100% of investment).

The sample of '**Other sectors**' included mainly large enterprises; the average turnover of this category is about 67 m€, which is 2.4 times higher than the average turnover of the total sample. The average number of employees of "Other sectors" is 270 employees and 1.7 times higher than the average number of employees of all 100 companies.

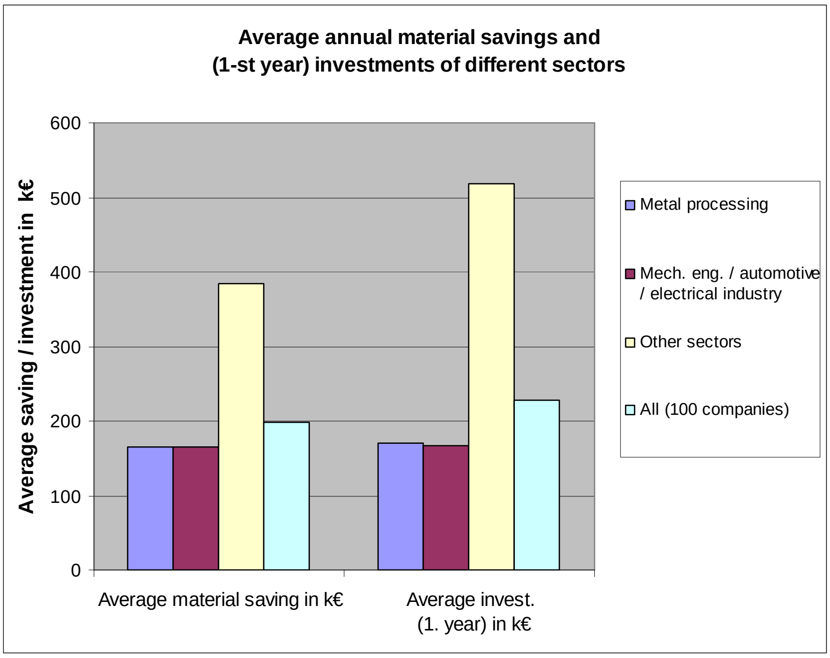

Fig. 4: Average annual material saving and investment per sector category

Average material savings per year and 1st–year investments in this sector category exceeded the average of the overall sample (Fig. 4). The average annual material savings is 385 k€ which is 1.9 times higher than the average of all sectors; average investments required exceed the average of the whole sample by a factor of 2.3. Due to this relatively higher investment the average annual material savings reach only 74% of average investment cost, hence resulting in payback time of 1.4 years. This corresponds to the correlations in Table 2, i.e. companies with higher turnover tend to have higher material savings and higher investments. Yet it should be noted that 'Other sectors' is a more heterogeneous sample and covers only 15 companies, i.e. the effects may be due to the small sample size and statistical significance may be not sufficient.

The average annual material savings and investments are increasing with turnover in **absolute values** (Table 2). Yet the **share of average material savings** and investments **related to turnover** decreases with increasing turnover. This

Turnover class	Average annual material saving in €	Av. 1st -year investment in €	Number of companies
< 2 Mill €	33,536	44,392	16
< 10 Mill €	103,207	99,612	30
< 50 Mill €	241,805	248,770	32
> 50 Mill €	337,744	451,569	20

Tab. 2: Average annual material saving and investment in relation to turnover

corresponds to the findings of a study performed by Wuppertal Institute on case studies performed until 2010.[13] A reason may be the fact that in larger companies the resource saving measures would cover only parts of the product portfolio or the departments of the company; hence the share of savings related to the company's turnover would also be smaller. For different turnover classes, the share of annual material savings in relation to investments is in a range of 75% to 100%. Accordingly, payback of first year investment can be achieved in most cases in about 1 – 2 years. It should be noted that individual companies may achieve very substantial material savings, with according ROI of less than one year.

Annual material savings in relation to material input

Overall, an average material saving potential of 7% has been identified, in relation to the material input in the companies' production processes. Looking at the frequency distribution of these relative material savings, more than 60% of the companies save more than 4% of their material input per year; more than one third of companies (35%) save more than 8% of their material input (Fig. 5). Annual material savings in relation to material input are highest for small companies and decreasing with company size (Fig. 6). One reason could be that the efficiency measures of larger companies may cover only parts of their production while smaller companies may tend to improve the whole factory.

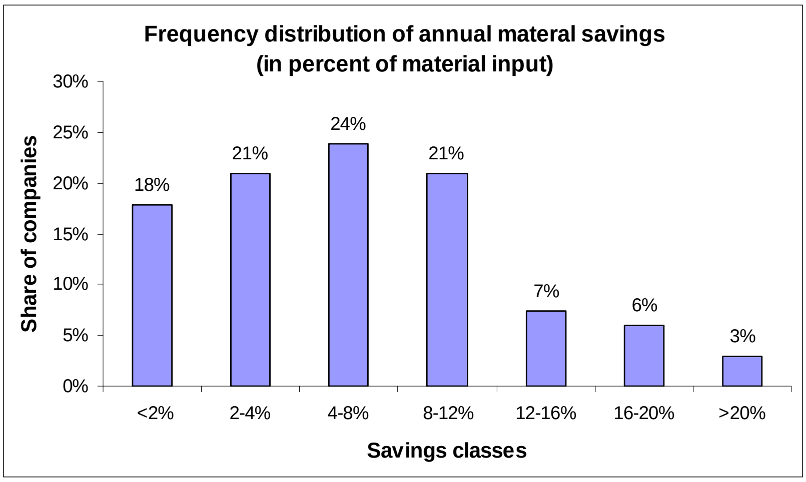

Fig. 5: Frequency distribution of annual material savings in relation to material input (in %).

Overall, significant yearly material savings have been demonstrated reaching up to 20% in individual cases.

Other resource savings

The German Efficiency programme is mainly focused on material savings. Yet, the measures implemented by the programme typically lead also to significant energy saving; also labour and production cost saving is often linked to the improvements.

About two third of the case studies have reported such other savings: on average these are reaching about 40%

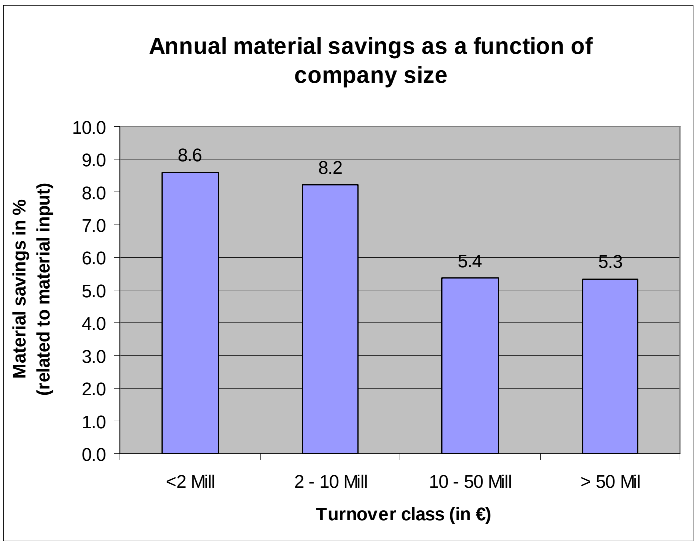

Fig. 6: Annual material savings in percent of material input per turnover class

[13] M. O'Brien, M. Miedzinski (2012)

of the related material cost savings[14]. Fig. 7 below exhibits average annual material savings and related other cost savings in comparison to required average investments. The figure shows clearly that, on average**, the investments pay off in less than one year when all cost savings are taken into account.**

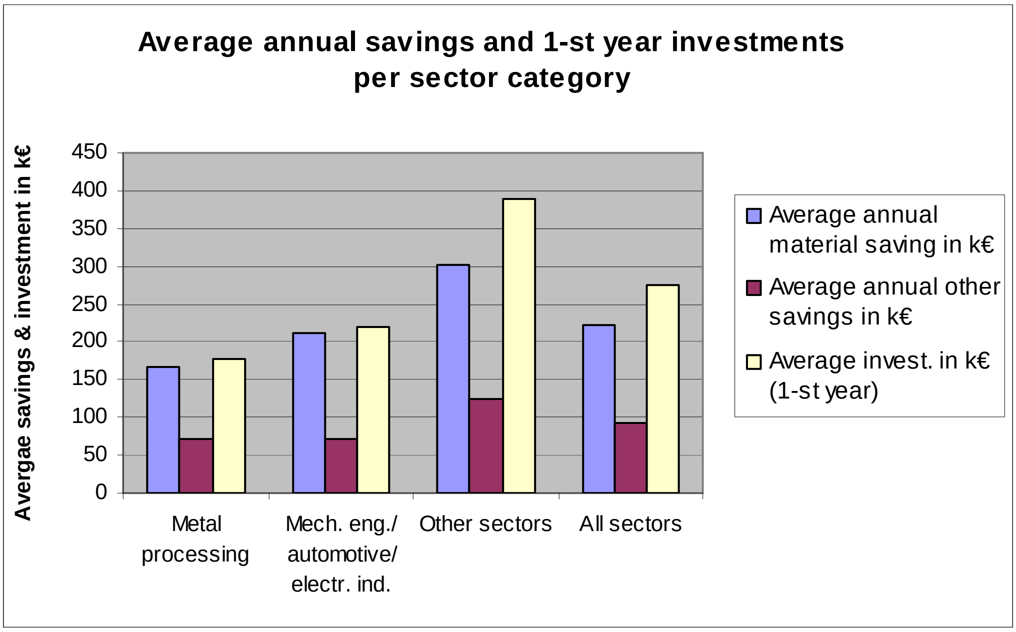

Fig. 7: Average annual material and other savings and related investments per sector

The effect of different types of measures to improve resource efficiency

The resource efficiency measures performed in the case studies typically fell into one of the following categories:

- Implementing new technologies
- Optimising production technologies and processes
- Optimising the production organisation
- Optimising the organisation of other areas (stock-keeping, logistics, purchase etc.)
- Training of employees
- Optimising external processes
- Product design

Companies could include multiple types of measures in one project, and in over 80 % of the case studies 2 or more measures have been implemented.

The **optimisation of production organisation** (76%) and the **optimisation of production technologies and processes** (64%) was a major focus of most companies. With measures on production organisation, average material savings of 191 k€ could be achieved at an average investment of 207 k€. Optimisation of production technologies led to average material savings of 247k€ at an average investment of 289 k€ (Table 3 below).

42% of the measures addressed the organisation of other company processes such as purchasing; stock-keeping; or logistic processes. Training of employees has been focused by only 30%, and even fewer case studies addressed product design, the implementation of

[14] Note should be taken that mean values are calculated only for those 66 data sets where data on both material and other savings were available, therefore mean values differ to some extent from mean values on all 100

new technologies or external processes (i.e. supply chain interfaces).

Type of measure	Average turnover in k€	Av. annual material savings in €	Average investment (1st year) in €	Number of comp.
New technologies	8,145	288,274	377,500	6
Optimimisation of production technology	35,511	246,744	289,388	64
Optimimisation of production organisation	22,450	191,432	207,562	76
Opt. of organisation / other businnes areas	16,680	157,193	158,962	42
Training of employees	22,487	116,773	115,156	30
External processes	10,992	21,882	46,018	5
Product design	24,367	227,274	209,425	18

Tab. 3: Number of measures types implemented per case example

Investment needs to increase resource efficiency

Table 4 shows material savings; other savings and average turnover in relation to investments. Both the savings and investments increase with increasing turnover. While a positive correlation between turnover and savings potential could be expected, this is not a causal relation since there could be other factors interfering (e.g. process technology, previous optimisation).

Investments in k€	Av. annual material saving in €	Av. annual other saving in €	Average turnover in k€
< 25	89,281	52,345	13,590
25-50	110,763	68,936	27,633
50-100	128,651	55,329	32,726
100-500	312,648	101,261	47,587
> 500	757,218	302,524	78,161

Tab. 4: Investments made and related savings

More important with regard to the leverage effect of resource saving investments, it seems that the share of material savings is decreasing in relation to investment costs with increasing investment:

- The share of average annual material saving related to average investment in the investment class '< 25 k€' is 530% (i.e. payback time of less than 3 months); while
- The share of average annual material saving related to average investment in the investment class '> 500 k€' is only 60% (i.e. payback time of 1.7 years).

companies in Table1 above.

Resource efficiency of manufacturing SMEs in the UK

Differences in the savings potentials related to industry branches and company sizes

To support the present evaluation and allow a comparison as close as possible to the demea study, a subset of the ENWORKS dataset has been utilised, incorporating only industry sectors that are broadly comparable to those featured in the German study. Due to differences in the key sectors represented in North West England and Germany, the UK case studies have been grouped into two branches rather than three:

- Aerospace / Automotive: This category summarises data from Automotive and Aerospace sectors, including suppliers and engineering companies
- Other sectors: This includes companies from the Chemicals, Food & Drink and Environmental Technology sectors, all manufacturing sectors with a significant presence in the North West

The third branch in the demea study, the metal processing sector, is not of sufficient significance in the North West to merit detailing as a separate industry sector; any such organisations will have been positioned under the appropriate manufacturing sector which they mainly supply, and so it can be expected they would be incorporated in one or other of the branches above.

The Table 5 provides a summary of the companies in the UK sample, by sector and size, and the average annual material saving achieved and the associated average investment required to realize the savings. For this comparison, the investment relates to one-off capital investment in the 1st year for the saving measure to be implemented.

Sector	Average Material saving in €	Average invest (1. year) in €	Size	Number of companies
Aerospace / Automotive	101,572	16,138	**SME**	10
Aerospace / Automotive	216,640	69,154	**Non-SME**	13
Chemicals / Environmental Tech / Food & Drink	90,059	18,780	**SME**	38
Chemicals / Environmental Tech / Food & Drink	73,293	85,473	**Non-SME**	29
All	150,652	47,323	**Both**	90

Table 5: Average annual material savings, investments and company size per sector category; SME definition according to EU standard (250 employees)

The Chemicals / Environmental Tech / Food & Drink category is the focus of the sample, with 38 SMEs and 29 large organisations featured for comparison. The Aerospace / Automotive grouping is smaller, with 10 SME and 13 Large companies included.

- Aerospace / Automotive companies, whether SME or large, achieve material savings significantly greater than their counterparts in the second group. Aerospace / Automotive SMEs saved an average 101 k€ for a first year investment of 16 k€ - such savings represent a compelling 600% return on investment, a payback period of less than two months.15 These results are on a par with the findings from Germany. Examples of typical measures implemented are shown in the box below.
- For SMEs in the Chemicals / Environmental Tech / Food & Drink sample, the first year investment is similar at 18.8 k€, with the average material saving being only slightly lower than their contemporaries in the Aero / Auto group at 90 k€; the return on investment is a very respectable 10 weeks or so.
- A similar pattern is evident in the comparison between large companies in both groups. Large

[15] These summary figures for the group exclude the results for one organisation which realised a saving of nearly 2 m €, which would otherwise disproportionally influence the findings for the average return on investment; including this saving the average ROI for the group increases to 1800%.

Aerospace / Automotive companies make annual savings around three times higher than those of comparable companies in the other sectors, but in both groups the first year capital investment required is markedly higher than for SMEs.

- In Aerospace / Automotive Large companies invest 4.3 times that of SMEs extending the return on investment to about four months. For Chemicals / Environmental Tech / Food & Drink Large manufacturers invest 4.5 times the value of their SME counterparts, resulting in a 14 month payback period.

For the sample group as a whole comparing annual average material savings for the SMEs against large organisations, the SMEs realize savings 1.5 times those of large organisations, for an investment less than 25% that required by the larger companies. The average return on investment reflects this, being less than three months for SMEs against 8 months for large companies.

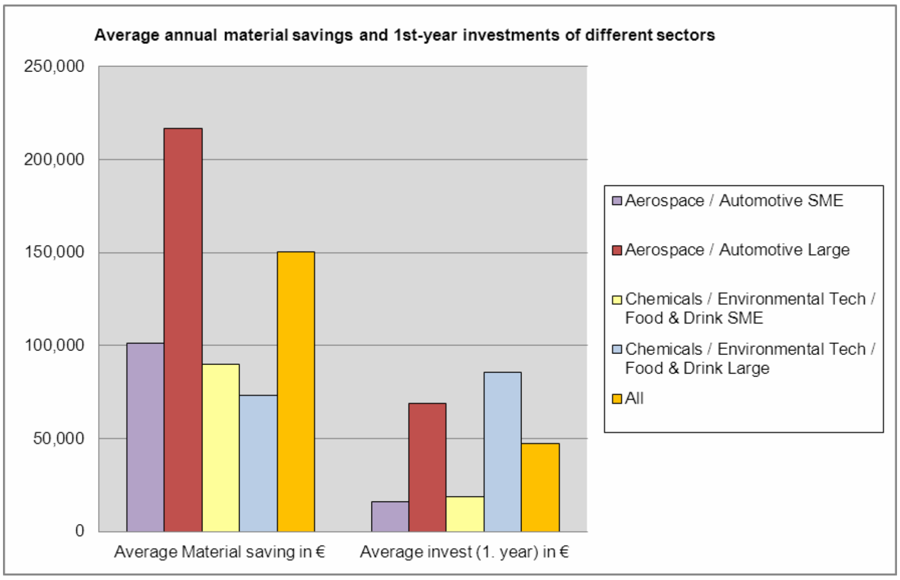

Fig. 8: Average annual material saving and investment per sector category

A reason why savings are seemingly more expensive to achieve in large organisations when compared to SMEs may be due to larger organisations having already identified and implemented the initial 'low-hanging fruit' savings opportunities; employing higher numbers of staff potentially results in individuals being specifically tasked with identifying cost savings, whereas in SMEs this is less likely to be the case. The companies in the ENWORKS dataset may be at different stages of their journey towards become a resource efficient manufacturing organisations when they join the programme to seek support.

Size	Average Material saving in €	Average invest (1. year) in €	Number of companies	Average ROI (years)
SME	179,517	18,359	48	0.10
Large	117,662	80,421	42	0.68

Table 6: Average annual material savings and investment SME vs Large companies

Other resource savings

In addition to raw material savings potential, the dataset provides access to details of other resource savings included energy (electricity, natural gas, fuel oil, and diesel), water and time. Within the sample group some 44 organisations had additional other resource savings and these are summarized in Table 7.

Compared to the material savings detailed in Table 8, there are significantly different trends apparent:

- Aerospace / Automotive SMEs realised an annual saving of 7.8 k€ from other resources, whereas raw material savings described earlier averaged 299 k€ per year, both for a near identical first year investment.
- For large Aerospace / Automotive organisations, the comparison is even more extreme, with an average saving of 4 k€ arising for other resources from an investment of 141 k€, a return on

investment of 35 years. It should be noted that the high average investment is mainly caused by an investment of 800 k€ by an Automotive company, which yielded total combined annual raw materials and other savings of nearly 175 k€. Excluding this figure would cause the average first year investment to fall approximately in-line with that of SMEs in this sector group (Fig. 9).

Sector	Average Other saving in €	Average invest (1. year) in €	Size	Number of companies
Aerospace / Automotive	7,836	16,643	SME	7
Aerospace / Automotive	4,098	141,727	Large	6
Chemicals / Environmental Tech / Food & Drink	17,783	5,352	SME	22
Chemicals / Environmental Tech / Food & Drink	31,127	30,278	Large	9
All	18,265	33,376	Both	44

Table 7: Average annual other savings and investment and company size per sector category

- The savings potential for Chemicals / Environmental Tech / Food & Drink SMEs is more favourable, although the average saving of 17.8 k€ is only 20% the equivalent value of annual raw material savings. Large companies in this sector group are able to make larger annual savings in energy and other costs of 31 k€ per year, 75% higher than SMEs, but the necessary investment rises by six times to 97% of the savings value. However, this is still an ROI of just one year.

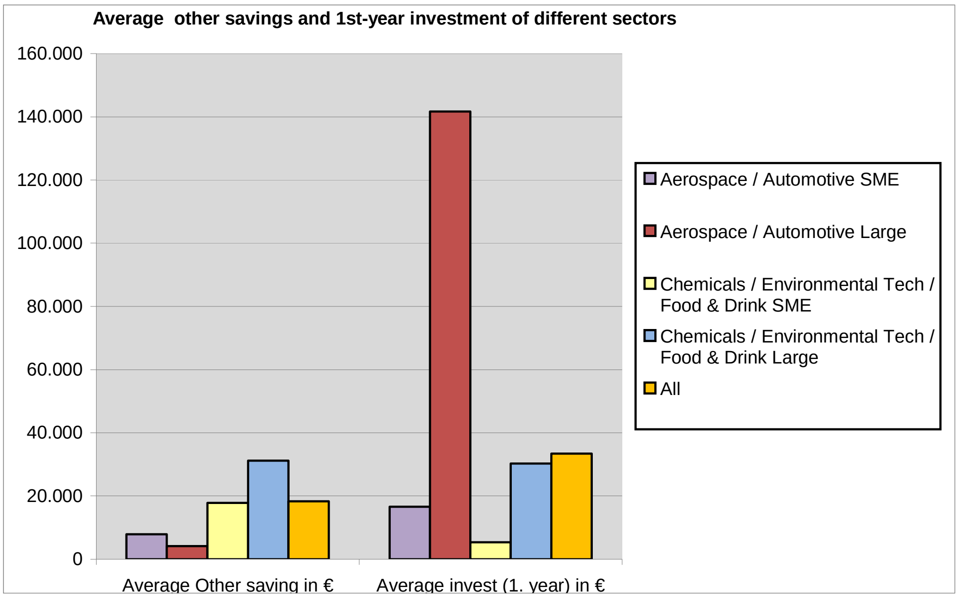

Fig.9: Average other savings and investments per sector category

The effect of different types of measures to improve resource efficiency

The available dataset identifies a range of measures that can be implemented to improve resource efficiency:

- Behaviour change
- Eco-design
- Environmental Technology
- Optimising production technologies and processes
- Optimising the organisation in other areas (procurement for example)

Multiple measures can be implemented by the same company (Fig. 10). As the ENWORKS Toolkit has developed over time additional indicator fields have been added. The measure (or method of resource saving as described in the toolkit) is a recently added section and the majority of eligible sector entries do not include this information. However, sufficient details are still available to allow interesting analysis to be made. NB: The information in this section relates to SMEs only.

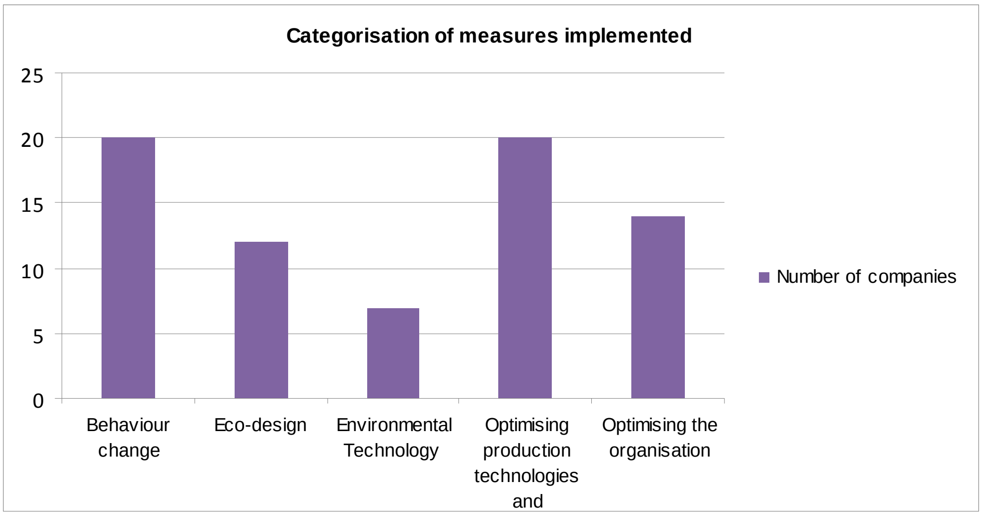

Fig. 10: Categorisation of measures (by number of SME companies)

The most highly adopted measures are to address behaviour change or the optimisation of production technologies and processes, with 20 companies addressing each of these themes. Optimising other aspects of the organisation, in particular procurement is the objective of 14 organisations, with 12 companies seeing benefit in adopting eco-design practices to improve resource efficiency.

- It is noteworthy that implementing behavioural change yields average savings of 15 k€ per annum, with no associated additional investment costs; suggesting that achieving specific resource-saving practices is treated as an on-going activity integral with general operations, rather than an additional cost-incurring action.
- Eco-design is another measure requiring minimal investment, and while average savings at around 7 k€ are half those achieved by behaviour change, it is unlikely that wider financial and environmental benefits in terms of potential improved sales, the in-use energy savings, end-of-life recycling improvements and so forth are captured in these figures.
- Environmental technology is addressed by only 7 companies, yet it yields an annual saving of 3 times the 1st-year investment.
- The saving potential for investing in optimized production technologies is skewed somewhat by a single saving opportunity of nearly 2 m€; without this the average saving for the 20 companies would be nearer 65 k€, still the most significant area of saving potential.
- Procurement improvements are the final category, with 14 organisations making an average of nearly 20 k€ savings per year as a result, an ROI of around 4 months.

	Average saving in €	Average invest (1. year) in €	Number of SME companies
Behaviour change	15,121	0	20
Eco-design	6,778	69	12
Environmental Technology	36,001	11,256	7
Optimising production technologies and processes	161,038	10,338	20
Optimising the organisation	19,686	6,589	14

Table 8: Impact of measures types

For every measure, companies recover their one-off investment in a matter of months, while savings should be realised year-on-year, making a compelling commercial argument for adopting any of these methods, regardless of the associated environmental and carbon reduction benefits.

Resource efficiency of European SMEs – results of a self-assessment

An online Self Assessment Tool (SAT) had been developed in the framework of the REMake project to help companies perform a simple first analysis of their resource efficiency performance and identify potential for improvement. Since this tool was mainly intended as decision support instrument, it includes a mix of subjective and objective questions. The answers to this questionnaire nevertheless provide relevant empirical data on resource efficiency performance and a European perspective, therefore a first analysis of these data has been included in this report. The results could help to understand better what company managers see as the most critical gaps in resource efficiency performance and what kind of support measures could help companies to improve their resource efficiency.

Until end of October 2012, 308 small or medium sized companies had used the self-assessment (Fig. 11). This is the basis of the present brief analysis which complements well the in-depth case study analysis described before.

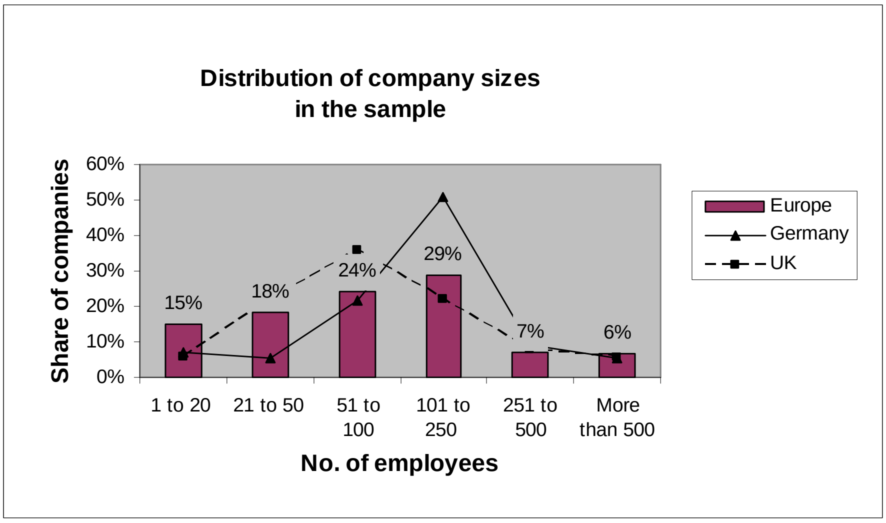

Fig. 11: Company size distribution in SAT analysis

The samples contain data from the following countries:

- Germany (55)
- France (99)
- Spain (68)
- UK (50)
- Italy (26)
- Other countries (10)

The main sectors addressed are:

- Manufacture of fabricated metal products;
- Mechanical engineering;
- Manufacture of rubber and plastic products;
- Manufacture of chemicals and chemical products;
- Manufacture of basic metals;
- Manufacture of electrical equipment.

The sector shares are more or less similar in most countries.

Overall results

The self-assessment questionnaire ("SAT") had been structured into four sections, each addressing a key business function, namely production; product development & design; management; and material / product handling functions such as purchasing, storage, packaging distribution. Each section consisted of an individual subset of detailed questions. Scores are given on each individual question; at the level of key business functions; and on the overall performance. For details, information of and access to the SAT is available at www.ecomanufacturing.eu.

On average, companies achieved an overall score of 49% while top performers typically reached 80 - 90%. The "Management" function achieved the highest average score (59%) while "Production" (46%) and "Product development & design" (45%) had lowest scores. This gives a first indication that companies have their deepest gaps in these fields. For a more detailed analysis and identification of priority measures to be taken by the companies, the scores of the individual questions on each key business function are discussed hereafter.

Resource efficient production

According to overall assessment "Production" has relatively higher potential for improvement of resource efficiency. A first question analysed the measures already implemented by the companies to reduce resource use (Fig. 12) over the last three years. Many companies have

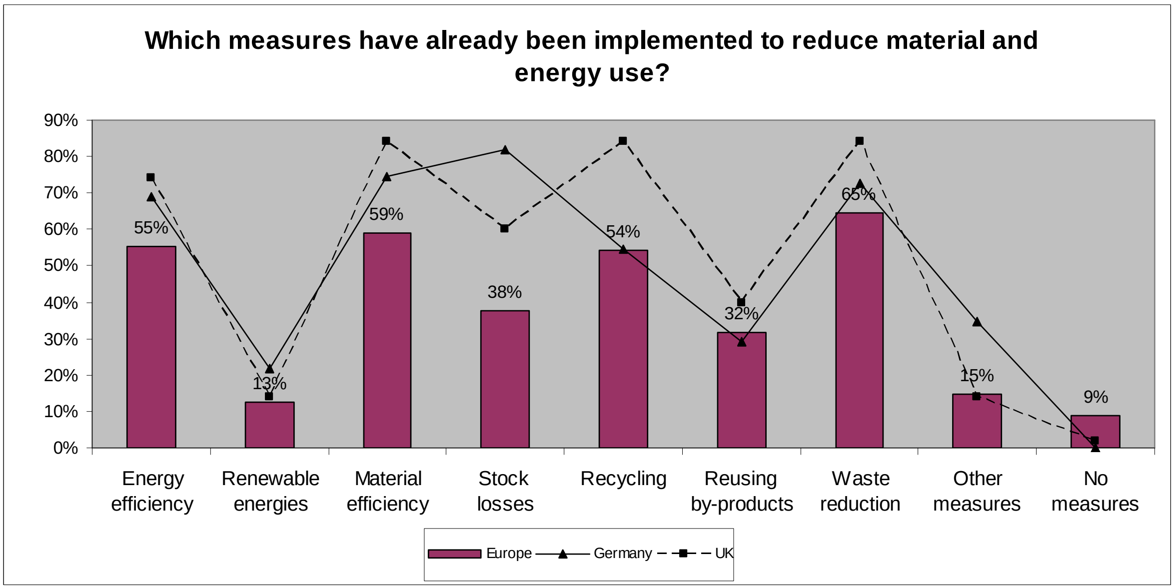

Fig. 12: Resource efficiency measures already implemented by the companies assessed

already addressed waste reduction, material efficiency, energy efficiency and recycling at least to some extent. The shares in Germany and UK are in most cases higher than the European average. In particular in Germany stock losses are reduced by 82% of companies compared to 38% on European average, whereas in UK material efficiency, recycling and waste reduction achieved highest scores.

Fig. 13 (below) shows different causes of scrap production. Human errors are seen as most critical (66%); followed by faults in set-up process (50%), and incorrect production documents (29%). Differences between the countries concern the relevance of human error in as a cause of scrap production which is highest in the UK and Germany.

Human error is seen as a relevant cause of inefficiencies, though most companies are satisfied with the way their employees are dealing with failures. In most companies line managers are informed when a failure is detected or the problem is immediately resolved by employees. In order to ensure the required **worker skills** to run manufacturing equipment with optimal performance, most companies only rely on teaching by experienced colleagues (61%). Additional training by equipment manufacturers is used by only 23% of companies and **regular qualification only by 16%** on the European average.

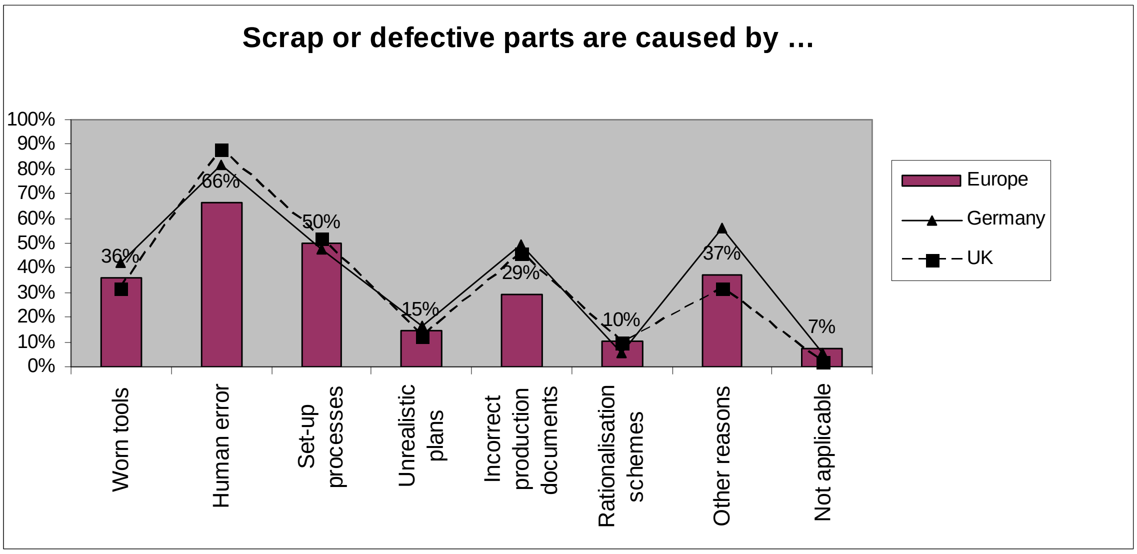

Fig. 13: Reasons for scrap production

Design & Product development

Ecodesign of products is a field not yet much addressed to improve resource efficiency. Only one third of the companies in the sample are undertaking this on a regular basis. Yet results for different countries partly differ. For instance in UK, the share of companies undertaking ecodesign improvement of their products is significantly higher than in Germany (Fig 14).

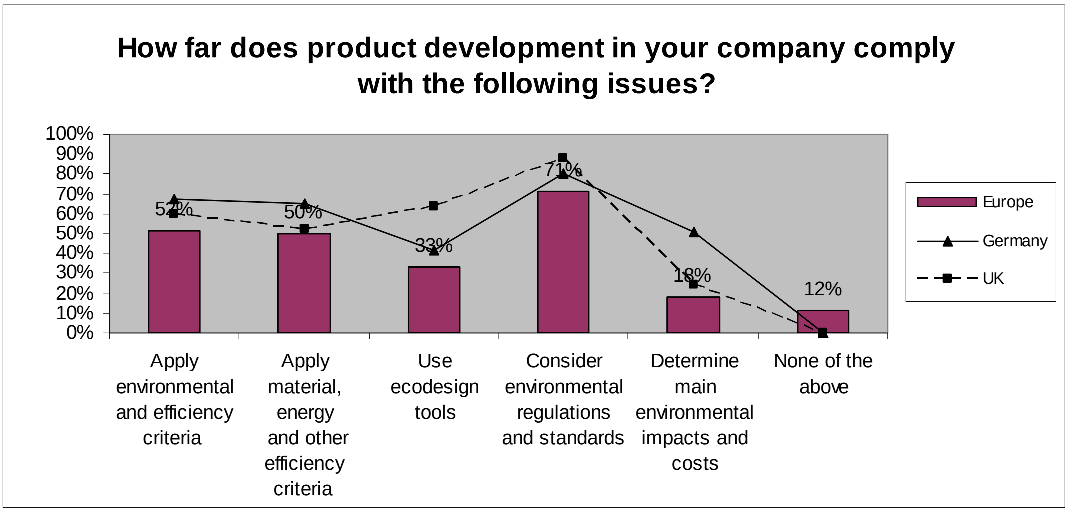

Fig. 14: Application of ecodesign criteria in product development

Environmental regulation and standards is critical for the majority of companies in the sample. To a high extent they integrate environmental and efficiency criteria or resource efficiency criteria alone in their product development, though specific ecodesign tools are only used to a lesser extent (33%). Only a small share of companies determine environmental impacts and costs during product development .Furthermore, most companies (66%) aim to use non-hazardous materials already in product design. A high share try to minimise weight and volume of products (53%) and enhance recycled content (42%).

Management

Management is the business function with highest overall scores. Accordingly, only a small part of companies (7%) have never undertaken measures to improve their internal processes in terms of environmental issues. Many companies state that insufficient cooperation between operational units of the company or between individual employees is sometimes (55%) or regularly (9) causing inefficiencies. Many companies also have problems with implementing lasting improvements, so that problems that have been solved sometimes (78%) or regularly (10%) may come up again. Most companies have an environmental policy at least to some extent, many have target setting and 43% even have an Environmental Management System implemented; with EMS scoring highest in UK (68%) and lowest in Spain (24%).

Energy monitoring is a key management issue for resource efficient manufacturing, Surprisingly, a rather high share of companies have no idea of their energy use (24%) or only know overall consumption data but are not monitoring the energy use of their processes (31%). This is in stark contrast to Fig. 15 where most companies stated they were managing resource efficiency in many ways. In UK even 38% of companies stated they have no knowledge of their energy consumption. Such knowledge would yet be the basis for in-depth improvement of energy efficiency. It could be assumed that the monitoring of material consumption will actually be not much better.

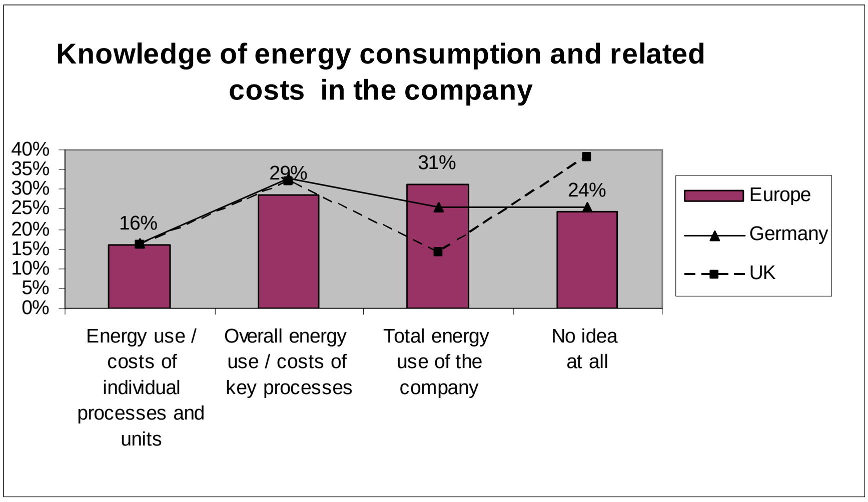

Fig. 15: Degrees of monitoring energy consumption

4 The resource saving potential of manufacturing value chains

Products and parts are manufactured today in a collaborative process of many companies across the different steps of an intermodal production chain. This has led to high complexity and many interdependencies hampering efficiency and flexibility. In order to reduce resource use, manufacturing costs and processing times, a **re-organisation and integration** of the whole manufacturing chain **across process interfaces** is essential. The interfaces between different process stages are critical for the integration of manufacturing chains: their optimisation requires considering the impacts and requirements of upstream and downstream processes to avoid defects and errors, and ensuring compatibility and reliability of across the whole production chain (Fig. 16).

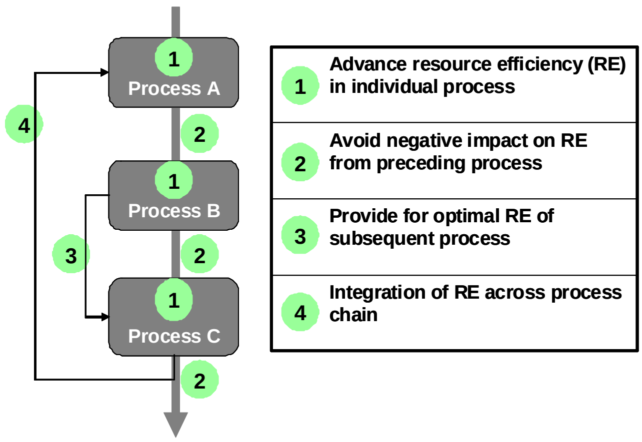

Fig. 16: Optimisation of production chains

Resource saving potentials over the manufacturing value chain can be identified by applying life cycle simulation of the current state and potential manufacturing alternatives. This is based on a modelling of the whole supply chain and analyses resource input (e.g. energy, materials etc.) and production output (products, losses, waste emissions) related to these alternatives. In the simulations of two manufacturing chains performed in this study, the according data had been provided by collaborating companies[16]. The following two manufacturing chains have been analysed:

1) 'Steel' manufacturing chain: producing hydraulic piston rods for construction machines and large hydraulic equipment;
2) 'Plastics' manufacturing chain: mass producing of plastic housings for household appliances such as electric kettles, electric irons, and other similar equipment.

Production Sector	Direct and indirect material use	
	in m t	in %
Construction	964	18
Food and feed stuff	465	9
Metal products	**459**	**9**
Machinery	**211**	**4**
Automotive parts & products	**335**	**6**
Chemical products	269	5
Others	2,181	42
Total	**5.289**	**100**

Table 9: Resource use of diff. sectors in Germany (H. Rohm 2008)

Basis for the selection of the two example manufacturing chains

Both selected sectors are characterised by high resource use and saving potentials, while significantly differing in materials and technologies used. Tables 9 and 10[17] exhibit relevant sector specific data from Germany; similar sector relevance has been reported in a recent UNEP study[18].

Sector	Material use (bn € p.a.)	Saving potential (bn € p.a.)
Metal products	18.6	0.8-1.5
Plastics products	10.8	1.0-2.0
Total	**61.8**	**5.3 – 11.1**

Table 10: Material use vs saving potentials in Germany (H. Rohm 2008)

[16] Where appropriate the simulation has been simplified if generalised data were available from according databases (e.g. for resource use of basic processes such as ore extraction).
[17] See for example H. Rohm et. al. (2008)
[18] UNEP (2010)

Metal mechanical manufacturing chain

In a simplified view, mechanical manufacturing is performed in a three-step intermodal production chain with the core steps being primary shaping, machining and surface engineering (esp. for corrosion / wear protection) as depicted in the graphic (Fig. 17).

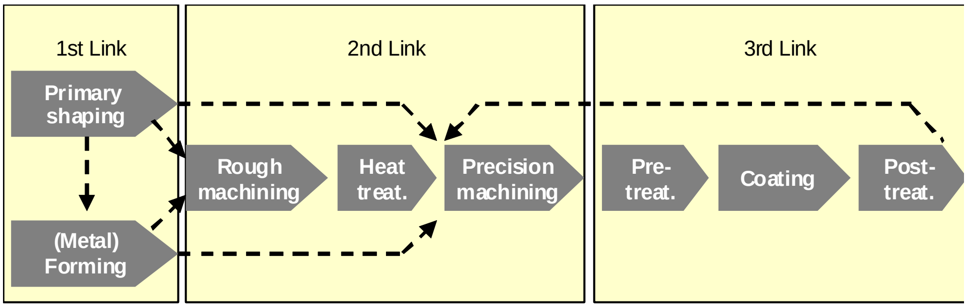

Fig. 17: Process chain metal forming / coating

Depending on the specific product, each of the three main steps may consist of sub-chains. In addition transport and storage, handling, cleaning, waste treatment etc. are linked to these main processes. Modelling of this production chain has to take into account all links between these process stages. Functional coatings created by advanced surface engineering more and more play an indispensable key role in this manufacturing chain.

As a typical manufacturing chain in this field, the production of stainless steel hydraulic piston rods with hard chromium coating has been selected. These products are widely used in machinery such as lifting devices, material handling equipment and construction machines. The manufacturing chain includes all steps from sophisticated steel making to precision machining to functional coating.

Life cycle simulation of this manufacturing chain has been carried out based on two different scenarios, a ‘best case scenario’ and a ‘conventional case scenario’. An important difference between the two cases was the use of low quality steel in the conventional case scenario vs high quality steel in the best case scenario as starting point of the simulation. The value chain model included the main elements as shown in Fig. 18.

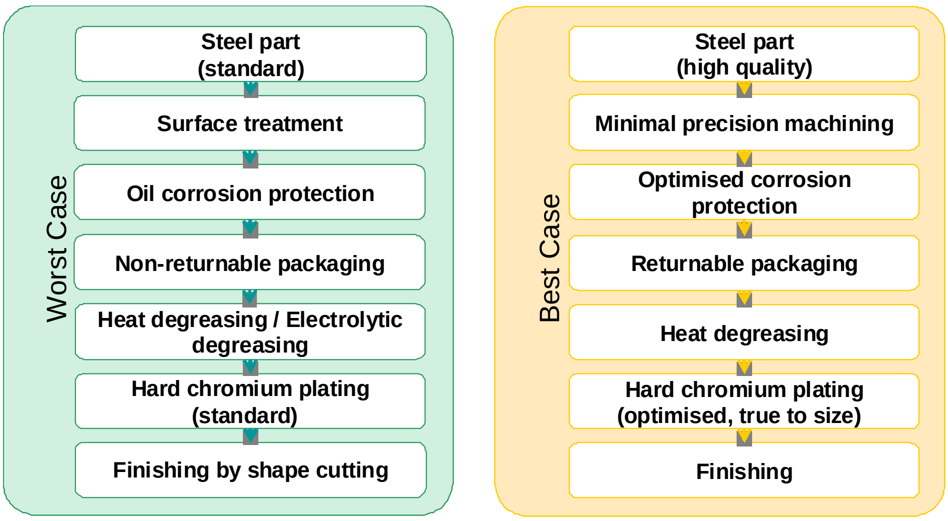

Fig. 18: Conventional case scenario vs. Best case scenario for the steel production chain

Steel casting and further upstream processes are not considered because they are the same for both scenarios.

The main differences between best case and conventional case scenario are the steel quality used as indicated above, possible optimisations of a number of relevant subsequent manufacturing steps due to improved steel quality, and new returnable packaging system for precision parts. All data of the simulation are related to the production of one average piece of hydraulic piston rod of about 1.5 m length and about 0.2 m diameter (0.6 m circumference). Detailed illustrations of the two manufacturing scenarios are provided in the Technical Study Document.

Fig. 19 exhibits the mass balance simulation results of the production of the steel body of a hydraulic piston rod, including forming, heat treatment and rough / precision machining; subsequent production steps are not considered here. The mass balance of the body part shows that by producing a higher quality steel part during heat treatment in the "best case" scenario, significant amount of scrap can be avoided because less machining (i.e. grade cutting) is necessary to reach the required surface quality of the steel.

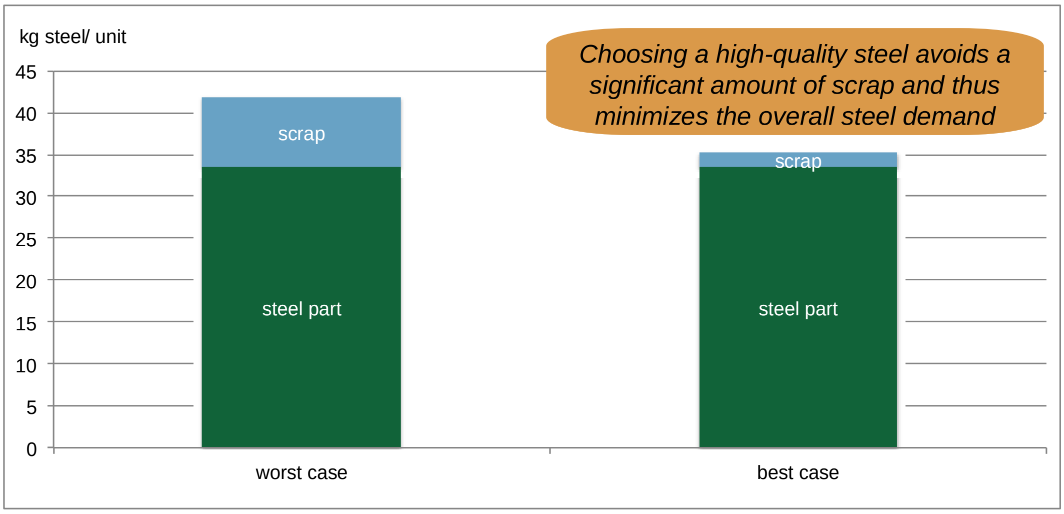

Fig. 19: Simulation results – Mass balance of the steel body of a hydraulic piston rod

Fig 20 (below) shows the total resource use of the analysed manufacturing chain; for easier comparison all resources (raw material, supplies, electricity etc) are transformed to primary energy consumption. The difference between best case and conventional case scenarios is very significant, amounting to 1,582 MJ per standard piston rod produced. This is equivalent to 38 kg raw oil consumption, corresponding to saving 55% of the primary energy load of the conventional case scenario.

The **absolute saving potential** is also significant: even looking only to the production figure of the hard chrome plating shop, an SME with about 50 employees coating 120,000 hydraulic piston rods per year, the total resource saving would be in the order of 4,500 tons of oil equivalent per year (corresponding roughly to a monetary saving in the order of 2 M€ p.a.).

Effect of manufacturing chain optimisation without factory level optimisation

The best case scenario includes an optimised hard chromium plating process which could also be implemented independently by the plating factory, without overall optimisation of the value chain. This would just require applying best available technology (e.g. form anodes, insolating cover plates, heat recovery, etc.).

The effect of this factory level optimisation was calculated by simulating a simplified best case scenario applying the same chrome plating process as in the conventional case scenario. In the chrome plating process the highest saving potential is in the electricity consumption.

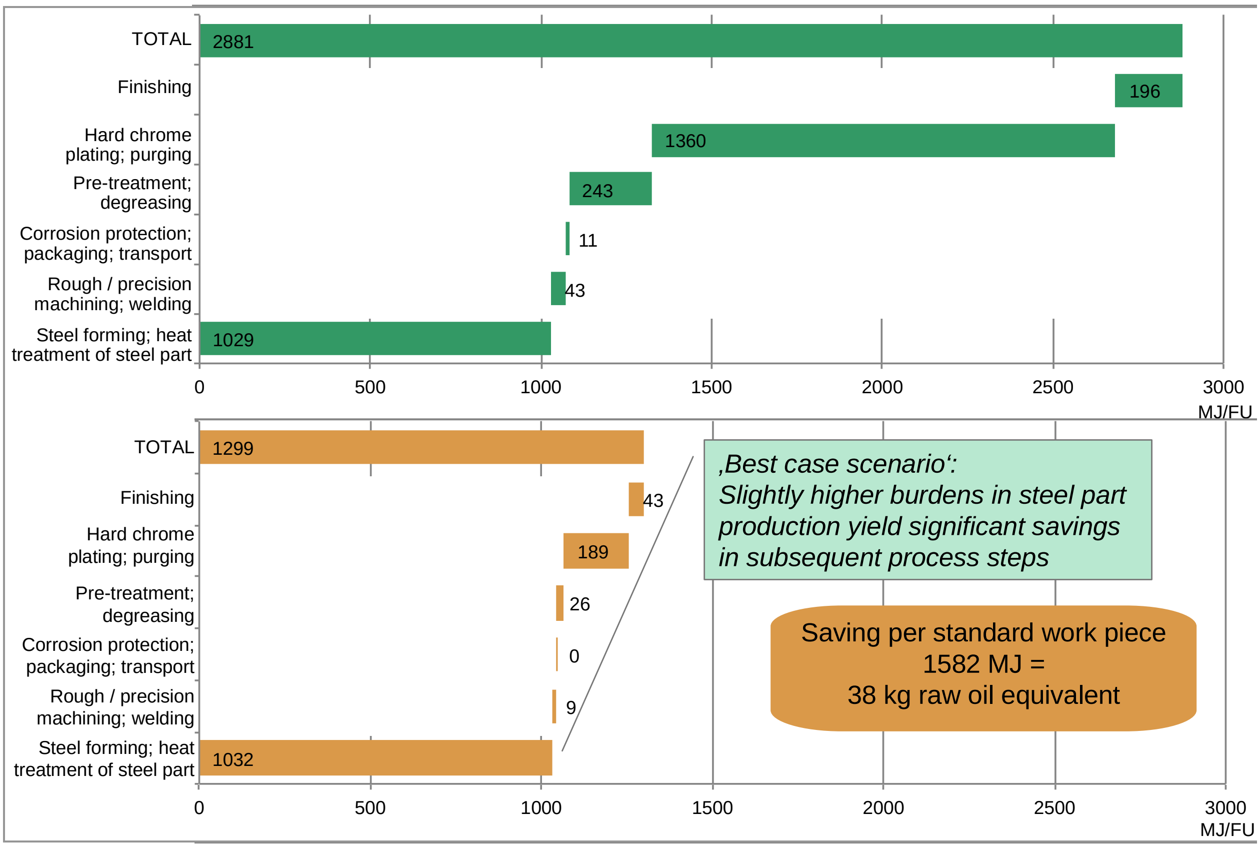

Fig. 20: Simulation results – Total resource use over the manufacturing value chain. All resources transformed to primary energy demand (in MJ). Above: Conventional case scenario. Below: Best case scenario.

The analysis revealed that process optimisation at the factory can **cut the energy consumption of chrome plating by one third** (from 286 MJ per standard product to 189 MJ per standard product). While this would already constitute a very substantial saving for the factory, **value chain optimisation would still have a much larger effect**. According to the simulation results, value chain optimisation could reduce the energy consumption at the chrome plating factory down to only 10% of the conventional case, and cut the total primary energy load over the value chain by half[19].

Hence, the potential impact on resource efficiency of the interface optimisation of this manufacturing value chain is striking. A slightly higher energy burden during the heat treatment of the steel part could lead to very significant savings in the subsequent steps of the manufacturing value chain. Very roughly estimated the monetary saving potential could be in the order of 2 M€ per year. This could be achieved at very limited investment cost since the optimisation measures involved are mainly organisational and changes of process parameters.

A more detailed discussion of the simulation results can be found in the Technical Study Document.

[19] A more detailed graphical explanation of the two scenarios is provided in the Technical Study document.

Plastic product manufacturing chain

In the manufacturing of plastic products the share of material cost in the overall production costs is 40% or more. The core steps of plastic part production are material pre-treatment and melting, forming and post-treatment. The forming processes used are depending on the specific product and include injection moulding (for formed parts), extrusion (for standard profiles), blow moulding (for hollow parts), calendering (for plastic films), casting and laminating (for compounds) as well as foaming. Processes linked to the core processing steps include material handling and storage, and other processes like waste, waste water or exhaust air treatment. Very often the plastics part will also be coated. Opportunities for increasing the material efficiency in plastic products manufacturing are mainly in the product design and in process development, while optimisation of existing processes has only a limited potential for further material saving.

As a typical example for a plastic manufacturing chain the mass production of plastic housings for household appliances such as electric kettles, electric irons, and other similar equipment was analysed. The production scenario of the conventional case consists of an injection moulding of the plastic housing and subsequent varnishing whereas in the best case scenario the housing is produced by film back injection moulding (Fig. 21).

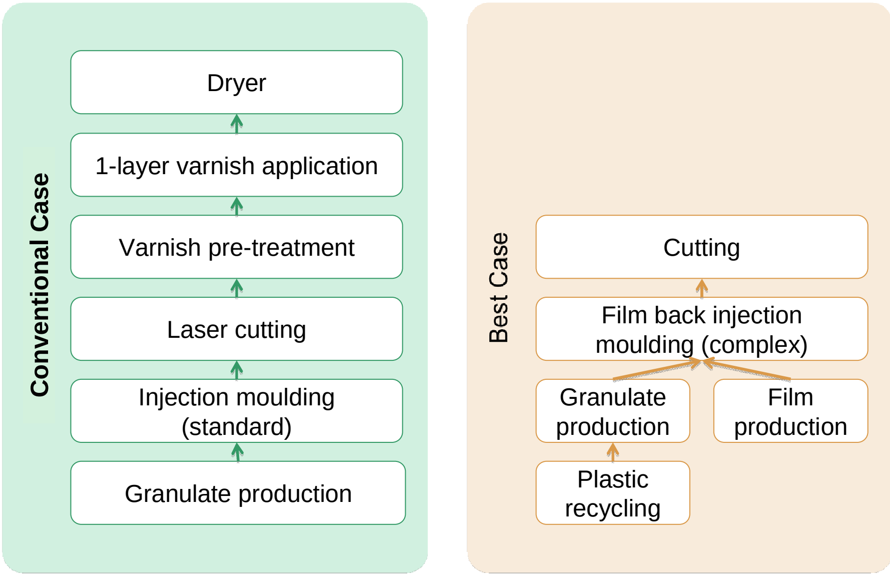

Fig. 21: Conventional case and best case scenario of the plastic production chain

The mass balance of the structural part (Fig. 22) shows significantly reduced material use. This is achieved by a redesign of the manufacturing value chain with a more advanced and complex technology for the core plastic processing. With this technology more complex structures with holes and notches can directly be fabricated, hence reducing subsequent cutting to a minimum. The best case scenario thus requires significantly less granulate as Fig. 53 clearly shows (though depicting only the production of the structural plastic component before painting / without cover film).

Moreover, film back injection moulding has lower requirements on the material quality of the plastic structure, since the film will cover the whole structure with a smooth and high quality surface. Hence, other than in the case of painting (conventional case) a significant amount of recycled plastic can be used. Very important, the painting process can be completely avoided, saving substantial amounts of energy for drying as well as material losses due to overspray in the painting process (typical 30% of paint is lost due to overspray).

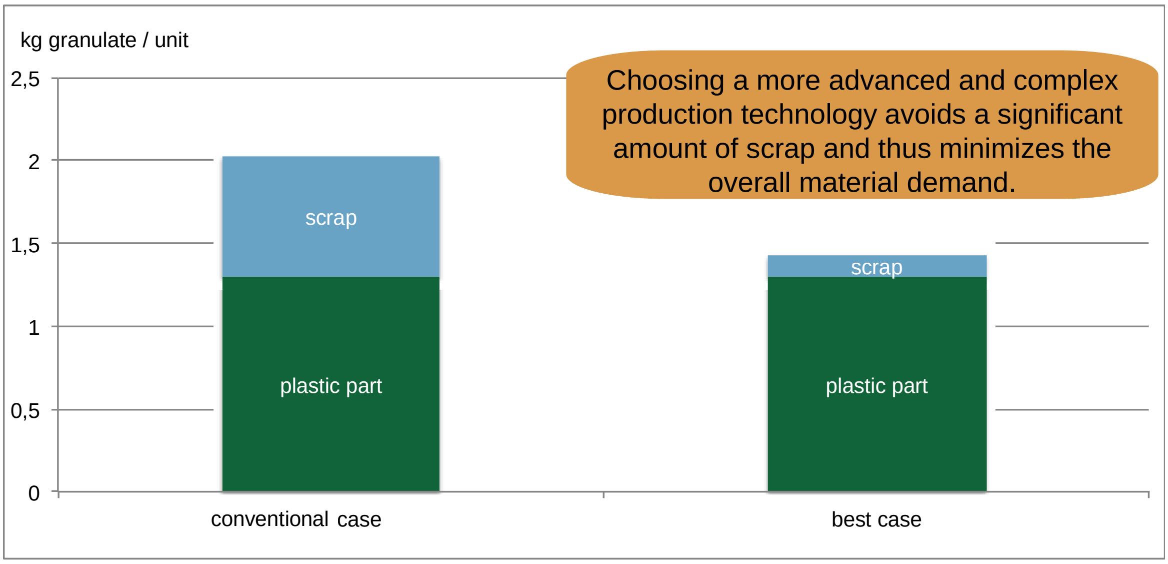

Fig. 22: Comparison of the mass balance of the structural plastic component (w/o recycling)

Fig. 23 finally exhibits the total resource use (materials, energy, waste etc.) over the plastic manufacturing value chain calculated as primary energy load (since the plastic materials can easily be translated into oil equivalent). The result is even more significant as in the metal mechanical case study: by re-designing the value chain a total saving potential of nearly 70% of resource consumption could be achieved. Key contributions are:

- Costs and efforts for the painting process are omitted (41%);
- More complex geometry possible in film back injection moulding allows material saving (15%);
- Possible use of recycled plastics (10% contribution; with recycled content of 25%);
- By avoiding the painting process the overall reject rate is also reduced (2-3%).

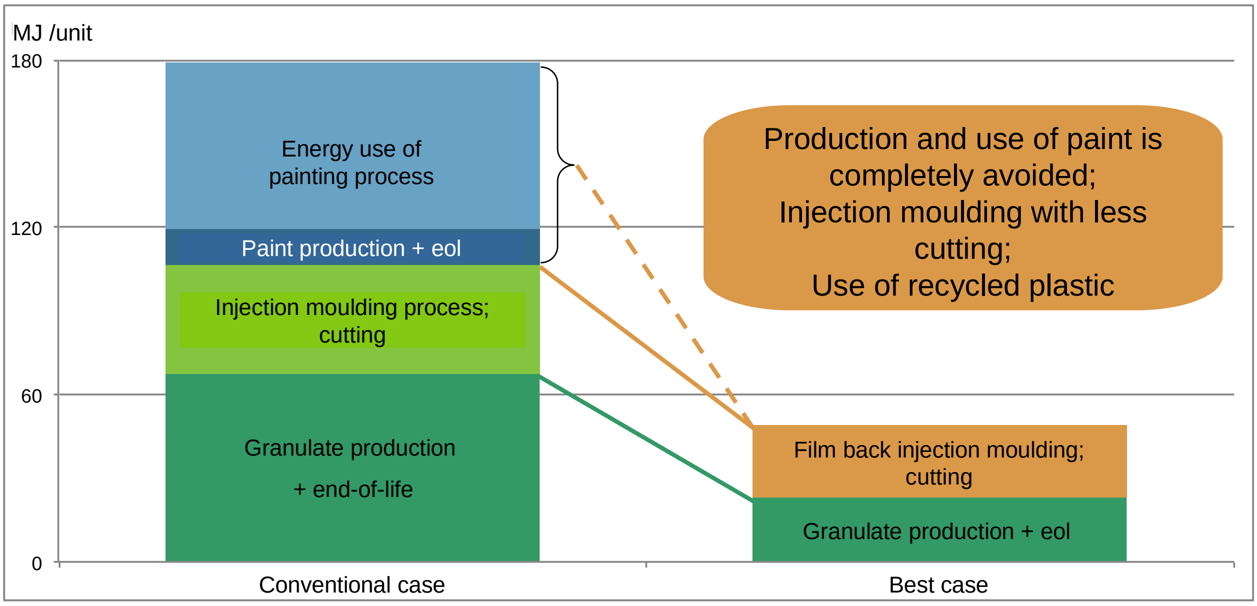

Fig. 23: Primary energy balance of the plastic housing

4 Conclusions

The analysis of '**factory level' resource efficiency** revealed average **material saving potentials of 7 – 10%** of material input and **total** resource saving potentials of 10 – 15% including energy, supplies and others. The case studies exhibited a wide distribution of results, with few companies achieving material saving of more than 20% (and up to 25 % total resource saving). Smaller companies in particular tended to achieve higher average relative material saving.

Other studies had estimated[20] that overall factory level material saving could reach up to 20% of total raw material consumption by applying best available technologies. According to the case studies results, the actual average saving potentials are reaching only half of this estimated value.

One important finding is the **strong interrelation in the use of materials and energy** and the related saving potentials. This is clearly pointing to the fact that a **separation of programmes for energy efficiency and raw materials efficiency would be suboptimal compared to approaches pursuing an integrated resource efficiency optimisation strategy.**

The state of play today in the manufacturing industry with regard to improving resource efficiency is focused on low cost, short term gains[21]. While the relevance of resource efficiency is regarded as high by most of the companies as confirmed by the SAT analysis, simple short term measures are generally preferred even if the saving potential addressed is comparably lower. This is consistent with findings of the case study analysis that most investments made for resource efficiency pay back within only one year. For the UK a very short payback period is the predominant theme across nearly all cases, with few examples of companies investing in more complex improvement measures with longer term gains.

A caveat needs to be introduced at this point. The analysis is based on data collected by business support programmes, which by nature of their funding are typically required to generate measureable economic results within a fairly short timeframe. Therefore it could be argued that the interventions progressed may to a degree be self-selecting as being those that will achieve the necessary metrics in time. To support businesses implement the more complex changes required to achieve long term gains, business support programmes with an extended five to 10 year duration and consistency of purpose may be beneficial.

Accordingly, the measures that have been implemented in the case studies were focused mostly on the optimisation of production technologies, production organisation and organisation of other areas such as employee training. Less used were measures implementing new technologies, optimizing product design and optimizing interfaces to external processes. This applies equally across manufacturing SMEs in Germany and the UK.

The optimisation of external processes has actually been undertaken very rarely and mostly in terms of improved coordination with suppliers. **It can be concluded that the potential of value chain optimisation is not well used by companies**; hence a significant saving

[20] E. g. ‚Preparatory study for the Germany Materials Efficiency Programme'

[21] This has also been documented in a study by Fraunhofer IAO in 2010.

potential is still being neglected. This has been well demonstrated by the analysis of two exemplary manufacturing value chains. Both **value chain simulations have shown resource saving potentials which are by a factor 5 higher** than those of single factory improvements.

- The analysis of the metal mechanical value chain showed total resource saving of about 55% compared to resource input. With all saving translated into total primary energy demand for easier comparison, saving of 1,582 MJ (or 38 kg oil equivalent) could be achieved for each produced piece (hydraulic piston rod). With an annual production of 120,000 piston rods by the analysed companies this amounts to a total of about 4,500 tons of oil equivalent[22].
- The best case scenario of the plastics product value chain exhibited an even higher saving potential of up to 70% of primary energy use (again also raw materials saving translated into oil equivalent). This is particularly due to the fact that both significant energy and raw materials saving could be achieved.

Hence, both examples of resource efficiency optimisation across manufacturing value chains exhibit much higher saving potentials than (the sum of) single factory measures. In view of the fact that both value chains had been selected based on industrial relevance this supports the assumption that value chain optimisation could be a very effective lever to improve resource efficiency.

Nevertheless, both types of measures will be required to achieve a sustainable and resource efficient production. This is because companies want to go for quick wins first before they approach more complex solutions. This is especially so since manufacturing SMEs have been slow to adopt resource efficiency measures, despite the clear environmental and economic advantages that can be achieved. This has been analysed in depth in the course of the REMake project[23]; with following reasons for this attitude identified as most relevant:

- A lack of **awareness** of SME decision-makers on opportunities to improve resource efficiency;
- Insufficient **data** such as benchmarking of production processes and alternative technologies, lifecycle data and impacts;
- **Knowledge gaps** concerning access to technologies and innovative solutions and between actors;
- **Insufficient incentive to invest** in resource efficient technology due to the complexity of integrating new technology into existing processes.

One additional aspect which has come out of the self-assessment questionnaires is the **critical impact of worker skills** on resource efficiency. Since commercial training offers or public support initiatives to improve worker skills in this field are rarely available today, company managers may regard any technical measures to improve resource efficiency as too difficult to implement in their company.

[22] If transformed to CO_2 footprint this is equivalent to about 14,000 (± 12%) tons of CO_2, depending on the conversion scenario (compare e.g. US DOE, Carbon Dioxide Information Analysis Center)

[23] The analysis is based on two sources: the feedback received from the implementation of voucher schemes to improve resource efficiency which have been carried out in France, Germany, Italy, Spain and UK; and feedback from several industrial associations based on queries among their member companies.

Finally, addressing **policy recommendations** what is most important is still a **better understanding of resource efficiency**. In this respect it is particularly critical to understand that all four dimensions to 'resources' – i.e. raw materials, energy, supplies and wastes – are equally important. This is because they are strongly interlinked in the production of a product and require integrated optimisation to get optimal results.

Another highly relevant issue is to address resource efficiency at the principle levels of innovation:

1. Resource efficient manufacturing and recycling processes **at single factories** which is highly cost effective and often pays off in less than one year;
2. **Eco-efficient product design,** enabling low resource consumption during product use as well as efficient manufacturing and recycling;
3. Integrated optimisation of the **manufacturing value chains** and especially of the interfaces between different production stages and different factories.

Most important for policy making, **resource efficiency is not just about energy** consumption or critical raw material substitution; it is about the most intelligent way of using all our natural and residual resources. Today the **different dimensions of resource efficiency are still addressed separately, missing the synergies of an integrated approach**.

Particularly for the UK, to allow a better understanding of the pressures and benefits around resource efficiency, a more comprehensive national database of the ebb and flow of raw material consumptions and costs would be highly advantageous. As was experienced during this project, the necessary information on manufacturing sector raw material consumption is not available from ONS; this information is not gathered at source as a discrete dataset, being instead collated with other general input costs and making subsequent accurate analysis impossible. An amendment to the ONS data gathering process to include specific raw material volume and value indicators would be a further recommendation from this study.

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