Resource Efficiency Potentials of Manufacturing Industries

A comparison of the resource saving potentials of single companies and manufacturing value chains

Technical Study Document

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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 majority of measures and approaches currently applied focus on optimising 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 savings. 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 the complex value chains\(^1\); and between different companies involved in production.

This study has two main aims;

(i) The evaluation of company level resource efficiency savings potential
(ii) The evaluation of the resource savings potential of two exemplary manufacturing value chains

(i) The evaluation of company level resource efficiency savings 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 resource savings of 7% had been achieved in relation to resources used in production by the companies analysed. The related total annual cost savings (i.e. for saved materials, energy, water, waste, and other supplies) typically exceeded one-off investment costs required to implement these savings. 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 from the UK’s Office of National Statistics. 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 resource consumption before optimisation was not feasible, data on the average annual material saving achieved and the associated average investment required to realize the savings 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

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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)“

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 savings 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 savings than mere company level improvement. Until now, little knowledge has been available about the actual savings 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 between 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% savings 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 are based on only two exemplar results, discussion shows that these results positively support the assumption of substantial savings 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 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 savings 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.

Finally, policy recommendations are presented for further initiatives towards improving resource efficiency in the manufacturing industry. Most important is a better understanding of resource efficiency 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.
Rationale of the study

Objective

The resource (i.e. materials and energy) 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. With natural resources becoming scarcer and critical raw materials and energy resources becoming more expensive due to increasing global competition, resource efficiency has become an important issue for the competitiveness of European manufacturing companies.

Present approaches to increasing resource efficiency in manufacturing companies are mainly focused on single process / single source (mainly energy) optimisation within the production chains. A wider and integrated optimisation is assumed to have significantly higher savings potential. A major assumption behind this study is that such a strategy should particularly include optimisation across the interfaces between different steps in complex production chains and between different companies involved in the overall value chain.

Little knowledge is currently available about the actual savings potential that could be unlocked by such value chain optimisation. Available studies have mainly estimated generic sector specific savings or analysed the potential from selected cross-cutting technologies. While, according to discussion with industry experts, the option of value chain optimisation for resource efficiency have not even been consistently studied in the automotive industry where this approach is most advanced and highly relevant.

This study therefore aims to provide a quantitative estimation of typical value savings potentials by analysing in detail two representative manufacturing chains The savings potentials will be compared with typical savings potential at single company level derived from an analysis of a sample of about 100 recent cases supported under the German Materials Efficiency Programme, and from Enworks in the UK. Finally, the study provides a short overview of the state of the art of measures and strategies to increase resource efficiency compared to the major needs of companies.

Study background

Globalisation, an increased world population, the rise of emerging economies is putting increasing demand on raw materials and energy resources. The impact of market distortions through induced limitations of resource availability as well as through trading effects is also increasing. As a consequence, costs for raw materials and energy are increasing worldwide, as shown for example by the HWWI index for costs of raw material (including energy). In 2011 the index increased by 22.4% compared to 2010, reaching a new maximum value. With regard to the overall need for industrial resource efficiency, the large increase of costs for bulk industrial raw materials like crude oil, coal, steel, aluminium and copper is of particular relevance. From a technological standpoint, the supply of some metallic and mineral raw materials like for example rare earths or platinum group metals are regarded as particularly critical since their availability is essential for rapid technology development in growth sectors.

\[\text{http://www.hwwi.org/home.html}\]
The strategic importance of a sustainable supply and efficient use of resources (materials, energy, water, etc.) for European industries has been analysed in relevant studies and policy documents; notably the EC Communication ‘Making raw materials available for Europe’s future well-being’\(^5\), the Europe 2020 Strategy including the ‘Resource efficiency’ initiative and associated roadmap on resource efficiency. The challenges and risks of supply shortages and inefficient use of resources which European industries and society as a whole may face in the future have led to the conclusion “that a continuation of ‘business as usual’ is no longer an option for Europe”\(^6\).

While the inherent complexity of the matter has widely been recognized, most initiatives so far are focusing only on parts of the whole picture with variations according to policy priorities of some European Member States. The main focus is still on the supply and use of energy resources. Second, the environmental impact of industrial production is being addressed, including increasingly the reuse and recycling of products and waste at end-of-life. This is now being complemented by initiatives such as the European raw material initiative\(^7\) and complementary national initiatives (e.g. the German Raw Material Strategy, the UK Resource Security Action Plan) which are focusing on the supply side of raw materials with particular emphasis on critical materials and the extraction and processing of raw materials.

Nevertheless, a significant challenge still remains to address material (including water) and energy efficiency jointly over the entire industrial value chain; including in particular SME manufacturing industries and taking into account costs as well as regulatory aspects. At company level, the adoption of strategies aiming to enhance the efficient use of resources contributes to lower costs and increases economic benefit as well as competitiveness. In this overall framework resource efficiency includes; the reduction of energy consumption and material use per unit of value added, the substitution of materials and critical substances, the reduction of wastes and emissions as well as increased reuse and recycling, and optimised transport and logistics. Together, these measures will be decisive for the future competitiveness of manufacturing industries as a whole as well as for each single manufacturing SME.

The scope of resource savings potentials in manufacturing

In the European manufacturing sector, total resource consumption accounts for about 45% to 50% of total production costs, compared to about 20% accounted for by labour costs (Fig. 1). According to data of the German Federal Statistical Office (2008) the share of materials and energy costs on the gross production

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\(^4\) M. Faulstich et. al.(2010); K. Rademaekers et. al. (2011)

\(^5\) Com(2012) 82 final

\(^6\) Com(2012) 82 final

\(^7\)http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm
value in Germany has increased from 31.5% to 44.6% between 2000 and 2006, whereas the share of labour costs has decreased from 21.4% to 18.8% in the same time (Fig. 2). Even looking at the manufacturing industry alone would show a higher increase of the share of resource costs.

As shown in Fig. 3 (depicting the development of labour, material and energy productivity in Germany from 1960 - 2000), labour productivity has increased much more than material and energy productivity. At European level, labour and material productivity vary considerably across the different countries. While resource productivity of EU-25 member states on average has increased by 2.5% per year from 1994 to 2000, its discrepancy from labour productivity has grown each year. The analysis also shows a clear impact of resource productivity on competitiveness and further potential for improvements in Europe.

Altogether, these analyses point to a considerable potential for boosting resource efficiency in European economies. Various studies have estimated quite substantial overall savings potentials of more than 20% of total abiotic resource consumption that could be achieved only by applying Best Available Technologies, summing up to about 900 bn Euro for major manufacturing industries. In this context the term ‘resource’ is encompassing raw materials, energy resources and all operating supplies required for value generation. Increasing resource efficiency involves thus an integrated reduction of the consumption of materials, energy, and supplies because these factors usually are strongly interlinked. Hence, benefits from increasing resource efficiency often may be significantly higher than estimated when looking at only one particular resource. For example, saving €1 of disposal costs may result in further savings of €7 – 12 of other costs due to the associated reduction in buying, processing and storing resources.

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8 Statistisches Bundesamt (2008); H. Rohn et. al. (2008)
9 R. Bleischwitz et. al. (2009)
10 Definition according to IPPC, Best Reference Documents (BREF)
11 see for example E. R. Baron (2005)
12 According to Effizienzagentur NRW (Efficiency Agency Northrhine-Westfalia), www.efanrw.de
The most important question in this context is how this saving potential can actually be realised. Savings achieved through shop floor measures in single companies are typically in the order of 10% of the firms’ resource consumption, as confirmed by the analysis of 100 company case studies below. This potential can easily be tapped by applying optimisation techniques and Best Available Technologies at company level. Yet there is obviously a gap between this typical firm level savings potential and the 20% resource savings potential identified by the aforementioned studies.

The assumption of the present study now is that this gap or an even higher savings potential could be addressed by optimising the interfaces between different processes and different companies of the increasingly complex manufacturing value chains. So far, this resource efficiency potential of value chain optimisation has only been analysed at macro-level across some industrial sectors. In contrast, this study is seeking to understand the savings potential of value chain optimisation through a life cycle simulation of two real-life production value chains typical of the manufacturing industries. Even though this could only be a first pilot approach it is expected to achieve relevant indications for future initiatives on resource efficiency improvement.

Three principal approaches to improve resource efficiency

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, addressing the whole value-chain of a product:

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

In a typical manufacturing SME such measures usually start with an improvement of the company’s manufacturing efficiency since this usually brings the quickest profit gains. The main characteristics of these three approaches are:

1) **Factory level improvement of manufacturing efficiency:**

Manufacturing processes transform raw materials and other inputs into finished products and in most factories there is still ample opportunity for energy and material efficiency improvements.

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. Larger changes are also highly profitable though they may require some investment. Yet, such investments often can pay off within less than a year.

2) **The product level - eco-efficient product (re-)design**

The design of a product strongly determines its life cycle impacts, starting with the selection

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13 R. Baron, et. al. (2005); Bayerisches Landesamt für Umwelt (2009); R. Erhardt, N. Pastewski (2010); K. Kristof, P. Hennicke et. al (2010)
of materials and finishing with recyclability at end-of-life. It has been shown that 70%\(^\text{14}\) - 80%\(^\text{15}\) of a product’s environmental impact throughout its life-cycle is determined at the design stage. Design decisions thus have a huge effect on resource consumption and environmental footprint, and in turn on the profits of the producer.

Resource efficient product design also has a logic that extends beyond reducing production costs; consumers are increasingly aware of the environmental impact of the products they purchase and respond accordingly. Eight out of ten EU citizens state that environmental impacts are either very or rather important to them when making decisions on what to buy.\(^\text{16}\)

3) ‘Level 3’ - 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’s input, requiring a great deal of 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 resource efficiency of a single process in the manufacturing value chain does not even necessarily imply an improvement of the overall life cycle resource 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 may be decreased. As another example, it may be appropriate to use a pre-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.\(^\text{17}\)

Yet due to the complexity involved there are very few companies who manage their whole production line in this way (including large automotive companies as stated above). As a consequence, little concrete information on actual savings potentials of typical manufacturing value chains is available which could motivate companies to invest in such optimisation strategies. A major goal of this study is therefore to contribute to overcoming this problem by providing more reliable estimations of savings potentials from typical, real-life manufacturing value chains.

\(^{14}\) Lowell Centre For Sustainable Production (2009)
\(^{15}\) European Environmental Bureau (2010)
\(^{16}\) Eurobarometer (2011)
\(^{17}\) compare also H. Walbaum, N. Kummer (2006); R. Neugebauer, D. López (2009)
Study Methodology

The study aimed at performing an exploratory analysis to demonstrate the resource saving potential of value chain optimisation compared to the potential of single company resource saving measures. Since there was no comparable theoretical or empirical study available on which this analysis could build, the design of the study approach has been part of the initial work. The results of this ‘pre-study’ are included in this report. Based on this the following overall approach has been chosen to achieve a quantitative estimation of the resource savings potential accessible through optimisation of typical manufacturing value chains.

1) Analysis of savings potentials at single factory / single process level
   - Statistical analysis of a sample of 100 case studies on resource efficiency optimisation. The case studies have been performed under the German Material Efficiency Programme in the context of the REMake project. For the present analysis case studies have mainly been selected from the metal mechanical and plastics processing sectors.
   - Analysis of statistical data on materials consumption and materials efficiency of manufacturing SMEs in the UK collected in a pilot survey. Such data are to date not available from the UK’s statistical office (see below for details) and were required for comparison with the German data.
   - Evaluation of results from 308 self-assessment questionnaires completed by SMEs on their resource efficiency performance. The self-assessment has been implemented under the REMake project and includes company data from several EU member states (DE, ES, FR, IT, UK).

2) Quantitative estimation of resource savings potentials of selected manufacturing value chains
   - In a pre-study, manufacturing chains from three industry sectors had 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 real life manufacturing companies. The savings potential of best available technologies, processes and business practices for different stages of the production chain have been simulated and compared to the as-is 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 (point 1) and value chain level savings potentials allows us then to draw conclusions on future priorities in designing resource efficiency strategies and initiatives.

Key issues of the approaches of points 1) and 2) above are hereafter described in some more detail.

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18 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.

19 The according two companies had agreed to analyse their manufacturing value chains and 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 any report or publication.
Analysis of company case studies from the German Material Efficiency Programme

A sample of 100 case studies from the German Materials Efficiency Programme (called ‘go-effizient’ and being one module of the so called ‘go-inno’ programme since August 2011) has been selected and an in-depth statistical analysis of the data has been performed. The sample has been selected from resource efficiency consultations performed during 2010 to present, and case studies have been taken mainly from the metal mechanical and plastics processing industries as well as automotive, machine building and electrical engineering. The sample also includes 30 case studies financed not as a grant to the companies but through innovation vouchers developed in the framework of the REMake project.

Types of data included in the analysis:

1) Company data such as industry sector, company size in terms of number of employees, annual turnover etc.

2) Economic data on resource use and savings potentials identified:
   - Materials and energy input
   - Other resource inputs
   - Resource savings:
     - Material savings,
     - Other savings: energy, labour costs and other cost savings, where available.

   The savings are mainly given in monetary units since physical units from different materials were difficult to compare and were not always available.

3) Type of measures selected to improve resource efficiency and the impacts achieved.

4) Investments required to implement the measures, both one-off and yearly investments.

All data is related to one production year; in this respect the following definitions are always valid also in case the yearly basis is not particularly mentioned:

- 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.

The resource savings potential of manufacturing value chains

Products and parts are in most cases manufactured today in a collaboration of many companies across the different steps of an intermodal production chain, which 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 would be essential.

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20 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.
As mentioned before, these interfaces between process stages are a most critical issue for production chain integration. An overall optimisation of the manufacturing chain will therefore have to consider the impacts and requirements of upstream and downstream processes to avoid defects and errors, and to ensure compatibility and reliability of the processes across the whole production chain.

As a first important step, measures to integrate a production chain will therefore include for instance standardised preventive quality management, integrated data management and documentation across the chain, validation checks, systematic measurement and testing, systematic failure cause analysis and linking-up of process control. SMEs in particular rarely have the competence and methods to implement such an overall system.

As a subsequent step, a life cycle approach to product manufacturing will show optimisation potentials from alternative technologies or material use. Such life-cycle assessment aims to identify potential environmental impacts of products along their whole life cycle. It is based on a modelling of the whole supply chain and analyses the resource input (e.g. energy, materials etc.) and the production output (products, losses, waste emissions). This requires a break down of the manufacturing chain into well defined “functional process units” (FPU, see graphic) and to build a theoretical model of the production chain by combining these FPUs through life cycle simulation. The optimisation of process interfaces and life cycle assessment for each FPU over the whole value chain has to ensure proper combinations of individual production processes to meet product design specifications. The different FPUs represent different technology or process alternatives, which may replace existing processes. Examples for such alternatives technologies or processes aiming to improve resource efficiency are described in the annex.

Manufacturing optimisation under a life-cycle perspective is a complex multi-objective optimisation problem. It will show possible ways to establish closed resource loops, thereby implementing the idea of a material-cycle based economy especially in SMEs. The LCA based methodology includes aspects like process description, data management and development of comparable process simulation and modelling approaches throughout the production chain, but also the development of appropriate assessment criteria. Like any other modelling methodology, the quality of the results of the LCA depends strongly on the quality and comparability of data sets used.

The present study aims to analyse selected production chains by comparing alternatives using different processes and technologies. Data on alternative processes and technologies have been carefully selected in order to ensure their appropriateness as well their comparability. Depending on the context, it may be useful to use average values of representative technologies, though for the purpose of this study the LCA had to include specific consumption data and resource flows to compare different alternatives for the modelled production chain. These specific data have been acquired through discussion with the companies involved in the selected real-life production chains.
LCA methodology, being a very flexible tool, is context dependent. The definition of the different modules and FPUs used depends on the aim for which the LCA is used. In the example of the graphic, the aims of an LCA at company level may be:

- To compare different production processes for the same product output (A);
- To compare the same product made of different materials (e.g. Steel vs. Aluminium), thus implying different production chains (B),
- To compare two different functional equivalents (C) such as the use of a large TV screen vs. a video projector for a slide presentation.

Each process module thereby represents the use of raw materials (M), energy (E), costs of transport (T) and recycling / disposal (R). The four different situations in the graphic are characterised by different aims, functional units, reference flows and life cycle stages (C. Bauer et. al (2007)). For the present analysis a combination of (A) and (B) has been applied in the simulation of energy and material flows of the production chains selected in order to estimate resource efficiency potentials. As a system boundary of the simulation scenario the ‘Cradle to gate’ case has been applied (Fig.7).
Evaluation of company level resource savings potentials of 100 German manufacturing SMES

The evaluation has been performed according to the methodological setting described above. The sample of 100 case studies was taken from several sectors with a focus on metal processing, machine building and automotive suppliers. All of the small and medium sized manufacturing companies analysed had received financial support from the German Resource Efficiency Program (managed by the German Materials Efficiency Agency, demea) to evaluate, plan and implement measures to improve resource efficiency with the help of technical consultants. The case studies were mainly focused on achieving material savings, though measures also contributed to savings in energy use, labour costs, or increase in production capacity.

All data used in the present evaluation have been collected from the detailed consulting reports which have been submitted to demea on completion of the consulting projects.

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

The case studies have been grouped in the following industry branches:

- Metal processing sector: 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.

Table 1 gives an overview on the number of companies in the sample from different sector categories as well as average material savings achieved, investments required in the first year as well as the average size (turnover and number of companies) per sector category. Average investments in the 1st year means thereby the one-off investment for the measure implemented plus potential yearly investments in the 1st year. The sample has a focus on metal processing companies, followed by the category machine / automotive / electrical industry.

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 Machine / 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:

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

Tab. 1: Average annual material savings; investments; company size per sector
• 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 category ‘Other sectors’ includes larger enterprises, only two companies have a turnover of less than 50 million €. The average turnover of this category is about 67 million €, 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.

Average material savings per year and 1st–year investments in this sector category exceed the average of the overall sample, too: 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.

![Average annual material savings and investment per sector category](image)

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

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

Tab. 2: Average annual material savings and investment of different turnover classes

Annual average material savings as well as average investments in absolute values are increasing with turnover, as the results of different turnover classes show (Table 2). Nevertheless the share of average material savings as well as investments related to average turnover in each class decreases with increasing turnover class: i.e. for companies with turnover less than 2 million €, average material savings correspond to 3% of average
turnover in this class, whereas for companies with a turnover of more than 50 million €, material savings are only 0.5% of average turnover in this class. This corresponds to the findings of a study performed by Wuppertal Institute on case studies performed until 2010.\textsuperscript{21} 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 related to investments is in the range between 75% to about 100%. Accordingly, payback of first year investment can be achieved in most cases in about 1 – 2 years. But it should be noted that in individual cases companies may achieve substantial material savings even with an ROI of less than one year. For example two companies achieved a material saving of 1.1 and 1.6 m€ for according investments of 970 k€ and 1.2 m€. On the other hand, another large chemical company needed investment costs of 2.9 m€ to achieve annual material cost savings of 511 k€ plus additional annual cost savings of 460 k€ mainly from energy saving.

**Annual material savings as a function of material input**

Data on material input was available from 71 companies of the sample and detailed analysis of material savings has been conducted on these firms. Overall, an average 7% material savings was achieved by the 71 companies investigated in relation to their material inputs. Looking at the frequency distribution of these relative material savings, 24% of companies are in the range of 4-8%. More than 60% of the companies save more than 4% of their material input per year, and more than one third of companies (35%) save even more than 8% of their material input (Fig. 9).

Although average annual savings and investments increase with the size of the company in absolute values, the annual material savings related to the material input are highest for small companies and decrease with the size of the company (Fig. 10).

\textsuperscript{21} M. O’Brien, M. Miedzinski (2012)
Companies with less than 2 m€ turnover achieved average annual savings of 8.6%, whereas larger enterprises with more than 50 m€ turnover could only save 5.3% of their material input. One reason for this may be that for larger companies the efficiency measures cover only parts of the company’s production lines while smaller companies may tend to improve across the whole factory.

Fig. 11 shows relative material savings for different sector categories. The mean value of material saving is highest for metal processing companies with 7.3% of material input while the machine / automotive / electrical industry sector achieves on average about 6.4%.

Data concerning material input was available for only 5 companies of the ‘Other sectors’ category, which is not representative (average savings account for 5.4%). This corresponds to the findings on turnover classes, that smaller companies achieve higher relative material savings.

Whereas average turnover of metal processing companies in this sample (71 companies) is about 16 m€, average turnover of the two other sector categories accounts for about 33 m€ (in this sample). Nevertheless it has to be noted that yearly material savings of the individual case examples differ in a wide range. Some companies achieve very high savings:

- **Two companies achieve yearly savings of more than 20%**: Both are from the metal processing sector.
  - One company achieves yearly material savings of 155 k€ (plus additional 720 k€ other savings per year, see below). The company has a turnover of 3.3 m€.
  - The other company achieves 23% savings per year with a yearly material saving of 1.05 million € and additional 190 k€ other savings per year for a 1st year investment of 970 k€. The turnover is 16 m€.
- **4 companies achieve yearly savings in the range of 16-20%** (one from metal processing, and 3 from mechanical engineering/automotive/electrical sectors) with material savings, investment and turnover in very different ranges.
- **5 companies achieve yearly savings in the range of 12-16%**

Some companies exhibit only very small savings, i.e. savings of less than 2% related to their material input. In most cases these are large companies (turnover more than 50 m€) and either from metal processing or machine / automotive / electrical industry sectors. They are dealing with expensive input materials like steel or aluminium. There is some indication that these companies may have smaller potential for improvements because they have already
implemented efficiency measures in the past in order to reduce their costs.

To summarise, while case studies are heterogeneous, overall significant yearly material savings have been demonstrated reaching up to 20% in individual cases.

**Material savings for different types of materials**

Fig. 12 shows yearly material savings in relation to material input for steel. Similar to the result for all materials, 64% of companies achieve more than 4% savings; 30% of companies achieve more than 8% savings; and 34% of companies are in the 4 to 8% range. For aluminium and other metals like copper, tin, zinc, brass etc. the ranges of savings are similar, but the data samples are small and will therefore not be discussed in detail. The sample of companies saving “other raw materials” like plastics consists of only 16 companies, but results differ in this case little from the results for metals.

As can be seen from Fig.13, in contrast to steel or the overall result for all materials, yearly savings of more than 8% are achieved by 36% of companies, and savings of more than 16% even by 18% of companies (steel: 6%, aluminium 12%, all materials 9%). The average material input of other raw materials accounts for about 2 m€ (steel 2.6 m€ and aluminium 3.9 m€).

Operating supplies such as adhesive agents, fillers, catalysts, curing agents, solvents, oil or purifying
agents exhibit on average lower cost savings of about 450 k€ per company in absolute figures (data available for 27 companies). Average annual savings are higher with 41% of companies achieving more than 8% savings and 26% of companies achieve even more than 20% annual savings (Fig. 14).

Other resource savings

The German Materials Efficiency programme is mainly focused on material savings. Yet, the programme does not only in generate material savings, the measures implemented by the programme typically lead also to savings of energy, labour costs (time), production costs etc.

In about 2/3 of the case studies analysed, additional information on other savings was available. These savings reach on average about 40% of the material cost savings. 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 companies in Table 1 above. For example, the average turnover here is for all sector categories higher than in Table 1.

<table>
<thead>
<tr>
<th>Sector category</th>
<th>Av. annual material savings in €</th>
<th>Av. annual other savings in €</th>
<th>Average invest. in € (1-st year)</th>
<th>Turnover in k€</th>
<th>Number of companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal processing</td>
<td>165,471</td>
<td>70,323</td>
<td>177,784</td>
<td>22,242</td>
<td>38</td>
</tr>
<tr>
<td>Mechanical eng.; automotive; electrical</td>
<td>211,275</td>
<td>71,014</td>
<td>220,487</td>
<td>32,481</td>
<td>14</td>
</tr>
<tr>
<td>Other sectors</td>
<td>301,095</td>
<td>124,584</td>
<td>389,161</td>
<td>68,094</td>
<td>14</td>
</tr>
<tr>
<td>All</td>
<td>223,009</td>
<td>93,697</td>
<td>275,343</td>
<td>33,079</td>
<td>66</td>
</tr>
</tbody>
</table>

Table 3: Average annual material savings plus other resource savings per sector category

![Average annual savings and 1-st year investments per sector category](image)

Fig. 15: Average annual material and other savings as well as investments per sector category

Table 3 and Fig.15 show average annual material and other savings as well as the average investments (in the first year) for different sector categories. It is to be noted that only 14 companies of the ‘Mech. eng. / automotive / electrical’ sector and “Other sectors” provided information on other savings, in contrast to 38 companies of metal processing sector.

For metal processing and ‘Other sectors’ the other savings (e.g. energy, water) on average reach up to 42% of the material savings. In mech. eng. / automotive / electrical other savings reach only 34% of the material savings.
In Table 4 and Fig. 16 below other resource savings are shown in relation to turnover classes. The share of other resource savings related to material savings decreases from 52% for turnover between 2 and 10 m€ to 30% for turnover >50 m€. In the turnover class of less than 2 m€ the other savings are varying in a large range from 8 k€ up to 200 k€ (related mainly to personnel cost savings), which is a very specific case.

<table>
<thead>
<tr>
<th>Turnover class (in €)</th>
<th>Average material saving in €</th>
<th>Average other savings in €</th>
<th>Average investment in € (1.year)</th>
<th>Number of companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2 Mill</td>
<td>25,549</td>
<td>55,193</td>
<td>53,143</td>
<td>10</td>
</tr>
<tr>
<td>2-10 Mill</td>
<td>121,237</td>
<td>62,911</td>
<td>111,555</td>
<td>16</td>
</tr>
<tr>
<td>10-50 Mill</td>
<td>214,786</td>
<td>96,420</td>
<td>247,331</td>
<td>21</td>
</tr>
<tr>
<td>&gt; 50 Mill</td>
<td>395,361</td>
<td>125,104</td>
<td>546,162</td>
<td>16</td>
</tr>
</tbody>
</table>

Tab. 4: Average annual material and other savings and investments per turnover class

It should be noted that the high average investment in the turnover class > 50 m€ is partially caused by two investments of 1.7 m€ and 2.9 m€. Both companies had comparably high turnover. The according savings accounted for 1.1 m€ of materials and 257 k€ of other savings; and 510 k€ of materials and 461 k€ of other savings in the second case.

The effect of different types of measures to improve resource efficiency

The different measures implemented to improve resource efficiency have been grouped in the following categories (Fig. 17 below):

- 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
Measures implemented in the individual companies could cover multiple categories. Most measures covered the **optimisation of production organisation** (76%) as well as the **optimisation of production technologies and processes** (64%). With measures on production organisation on average material savings of 191 k€ have been achieved (investment 207 k€), measures to optimise production technologies achieve average material savings of 247k€ for an investment of 289 k€ (Table 5).

42% of measures address the **optimisation of organisation** of other company processes (stock-keeping, logistics, purchase etc.) and 30% the **training of employees**. Companies implementing training of employees achieve **average material savings** of about 117 k€ for an investment of 115 k€. Measures optimising organisation achieve on average material savings of 157 k€ for an investment of 159 k€. Only a **few case studies** address **product design** (18 companies), the implementation of **new technologies** (6 companies) and the optimisation of **external processes** (5 companies).

Although sample sizes are small, the average values will be discussed hereafter: The measures on new technologies and external processes are mainly implemented by smaller companies: Except in one case example, turnover of companies implementing these measures is below 20 m€. The size of companies implementing measures concerning product design varies widely.

**Fig. 17: Categorisation of measures implemented**

**Tab. 5: Number of measures types implemented per case example**

<table>
<thead>
<tr>
<th>Type of measure</th>
<th>Average turnover in k€</th>
<th>Av. annual material savings in €</th>
<th>Average investment (1st year) in €</th>
<th>Number of comp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>New technologies</td>
<td>8,145</td>
<td>288,274</td>
<td>377,500</td>
<td>6</td>
</tr>
<tr>
<td>Optimisation of production technology</td>
<td>35,511</td>
<td>246,744</td>
<td>289,388</td>
<td>64</td>
</tr>
<tr>
<td>Optimisation of production organisation</td>
<td>22,450</td>
<td>191,432</td>
<td>207,562</td>
<td>76</td>
</tr>
<tr>
<td>Opt. of organisation / other businnes areas</td>
<td>16,680</td>
<td>157,193</td>
<td>158,962</td>
<td>42</td>
</tr>
<tr>
<td>Training of employees</td>
<td>22,487</td>
<td>116,773</td>
<td>115,156</td>
<td>30</td>
</tr>
<tr>
<td>External processes</td>
<td>10,992</td>
<td>21,882</td>
<td>46,018</td>
<td>5</td>
</tr>
<tr>
<td>Product design</td>
<td>24,367</td>
<td>227,274</td>
<td>209,425</td>
<td>18</td>
</tr>
</tbody>
</table>
The investments and material savings are very heterogeneous for the different case examples for these three types of measures. The implementation of new technologies achieves on average the highest material savings but requires also highest investments.

Measures including the *optimisation of external processes* are mainly implemented by small companies and address either an optimised coordination with supplier (e.g. omission of packaging) or optimisation of external processes (e.g. external picking), but not an optimisation of the processes of the value chain at all. In all cases investments are very small and result also in small material savings.

Most companies implemented measures addressing 2 types of categories (43 comp.), followed by 3 types of measures (33 comp.) Only 7 companies implemented 4 or more measure types and 15 companies address only 1 measure type (mostly optimisation of production technologies, 2 companies implement new technologies and 1 company a product design measure).

**Investment needs to achieve the resource savings**

Investments costs were not available in all case studies. Table 7 shows material and other savings as well as average turnover for different investment classes. 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).

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).

For a better understanding why the latter investments are still meaningful several very high investments of more than 1 million € are detailed hereafter:

- Investment of 2.9 m€: A chemical company with a turnover of 216 m€ achieved material savings of 510 k€ and other savings of 461 k€. The measures undertaken were focused on optimisation of production process technology.

<table>
<thead>
<tr>
<th>Investments in k€</th>
<th>Av. annual material saving in €</th>
<th>Av. annual other saving in €</th>
<th>Average turnover in k€</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 25</td>
<td>89,281</td>
<td>52,345</td>
<td>13,590</td>
</tr>
<tr>
<td>25-50</td>
<td>110,763</td>
<td>68,936</td>
<td>27,633</td>
</tr>
<tr>
<td>50-100</td>
<td>128,651</td>
<td>55,329</td>
<td>32,726</td>
</tr>
<tr>
<td>100-500</td>
<td>312,648</td>
<td>101,261</td>
<td>47,587</td>
</tr>
<tr>
<td>&gt; 500</td>
<td>757,218</td>
<td>302,524</td>
<td>78,161</td>
</tr>
</tbody>
</table>
Investment of 1.22 m€: A brewery with material savings of 1.59 m€ and other savings of 541 k€. The measures undertaken were focused on organisational optimisation of the production and other business function as well as on training of employees.

Investment of 1.74 m€: A manufacturer of fabricated metal products with a turnover of 8.5 m€ achieved material savings of 1.13 m€ and other savings of 257 k€. The measures implemented addressed the optimisation of technologies and organisation of production.

Except for the first company, all companies have achieved very high material savings of more than 1 m€ saving with these measures. Two other examples with material savings of the same order of magnitude concerned:

- One company from surface engineering with 22.7 m€ turnover achieved material savings of 1.21 m€ with an investment of only 205 k€. Measures included the optimisation of process technologies and overall business processes including the interfaces to customers and suppliers.
- Another manufacturer of fabricated metal products with a turnover of 16 m€ achieved material savings of 1.06 m€ and other savings of 194 k€ through an investment of 970 k€. The measures undertaken addressed the optimisation of production organisation and training of employees.

Results from an analysis of resource efficiency measures of manufacturing SMEs in the UK

A pilot survey has been developed and promoted in the UK to collect statistical data on materials consumption or materials efficiency of manufacturing SMEs. Such data are required for comparison with the German data but currently the necessary data is not available from the UK’s Office of National Statistics. At present ONS combines information at source on the purchased value of raw material consumption along with goods and services, making it impossible to subsequently extract specific details on industrial material consumption.

Due to the unfortunately negligible response by companies to complete the pilot survey, instead access to an existing resource savings dataset was provided by ENWORKS, distilled from their extensive Efficiency Toolkit database. Formed in 2001, ENWORKS has engaged with businesses of all sizes and sectors in the North West of England, providing practical advice, awareness-raising activities, on-site support and training, aimed at creating cultural change and environmentally sustainable business practices. For each of the nearly 10,000 businesses registered, the Efficiency Toolkit provides details of the economic and environmental impacts of identified resource efficiency improvements that can or have already been implemented; the Toolkit captures data for each individual intervention including; company sector, capital costs of improvement measure, type of material resource involved, the actual savings made in raw material tonnage, financial and CO₂ terms.

All data in the Efficiency Toolkit has either been entered by an ENWORKS advisor directly, or verified by an advisor after a business has entered the data themselves at the completion of an improvement project.

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22 Screen shots of the on-line survey are attached in Annex 3
23 The responses to the survey numbered only 2.
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 demeau 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 demeau 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 8 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.

The average material savings values have been compiled solely for data relating to resource reduction i.e. raw material savings from improvements in the manufacturing process or in packaging. The data gathered during ENWORKS interventions does not include figures for company annual turnover, the number of employees or material inputs, so comparisons cannot be made in these areas.

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 can save 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 years.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Average Material saving in €</th>
<th>Average invest (1st year) in €</th>
<th>Size</th>
<th>Number of companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerospace / Automotive</td>
<td>101,572</td>
<td>16,138</td>
<td>SME</td>
<td>10</td>
</tr>
<tr>
<td>Aerospace / Automotive</td>
<td>216,646</td>
<td>69,154</td>
<td>Non-SME</td>
<td>13</td>
</tr>
<tr>
<td>Chemicals / Environmental Tech / Food &amp; Drink</td>
<td>90,059</td>
<td>18,780</td>
<td>SME</td>
<td>38</td>
</tr>
<tr>
<td>Chemicals / Environmental Tech / Food &amp; Drink</td>
<td>73,293</td>
<td>85,473</td>
<td>Non-SME</td>
<td>29</td>
</tr>
<tr>
<td>All</td>
<td>150,652</td>
<td>47,323</td>
<td>Both</td>
<td>90</td>
</tr>
</tbody>
</table>

Table 8: Average annual material savings, investments and company size per sector category; SME definition according to EU standard (250 employees)

months. These results are on a par with the findings from Germany (please see page 23). Examples of typical measures implemented are shown in the box below.

### Three typical examples of improvement actions performed by automotive SMEs

<table>
<thead>
<tr>
<th>Required capital expenditure</th>
<th>Company 1: Process efficiency improvement which resulted in a 0.5% reduction in annual copper use, resulting in a raw material saving of 4.5 tonnes per annum (equivalent to 13 k€ per annum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero capital expenditure by the business</td>
<td>Company 2: Process efficiency improvement which involved the reuse of solvent on production lines and led to savings of 5 k€ per year</td>
</tr>
<tr>
<td>Very low capital expenditure (&lt;120 €)</td>
<td>Company 3: Improvement to the businesses procurement process reduced the amount of stock of composite materials held in storage and the costs incurred through loss of damaged stock, saving some 30 k€ per year.</td>
</tr>
<tr>
<td>Initial investment of 1 k€</td>
<td></td>
</tr>
</tbody>
</table>

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 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.

![Average annual material savings and 1st-year investments of different sectors](image)

**Fig. 18:** Average annual material saving and investment per sector category

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

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.

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 10.

In comparison with the material savings detailed in the previous 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 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.
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.

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. 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.

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.

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. The majority of companies implement a single measure (50 companies),

<table>
<thead>
<tr>
<th>Categorisation of measures implemented</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behaviour change</td>
</tr>
<tr>
<td>Number of companies</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 11: Number of measures types per case example</th>
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</thead>
<tbody>
<tr>
<td>Behaviour change</td>
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<tr>
<td>-----------------</td>
</tr>
<tr>
<td>Behaviour change</td>
</tr>
<tr>
<td>Eco-design</td>
</tr>
<tr>
<td>Environmental Technology</td>
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<tr>
<td>Optimising production technologies and processes</td>
</tr>
<tr>
<td>Optimising the organisation</td>
</tr>
</tbody>
</table>
with 10 companies adopting two and a single company three. The average saving from a single measure is 28.5 k€ with an associated investments of just over 3 k€, a saving of 9.5 times.

As might be expected, companies adopting two measures invest more. While the average value of the investment at 22.7 k€ is nearly 7 times that of companies adopting a single measure, this is more than offset by an average annual saving of 178 k€. The sample size of a single company implementing three measures does not allow any conclusions to be reached, beyond that they have achieved excellent value for money saving 27.5 k€ for zero investment.

<table>
<thead>
<tr>
<th>Number of measure types</th>
<th>Average saving in €</th>
<th>Average invest (1. year) in €</th>
<th>Number of SME companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28,499</td>
<td>3,284</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>177,806</td>
<td>22,692</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>27,500</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 12: Number of measures types per case example

Results from a self-assessment of 300 European SMEs with regard to their resource efficiency performance

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 dedicated 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. This is the basis of the present brief analysis which complements well the in-depth case study analysis described before.

The data 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. Some differences occurred in Italy with a higher share of companies in the rubber and plastic product sector; Spain with more
companies making fabricated metal products; UK with more electrical equipment manufacturers; Germany more mechanical engineering; and more French companies in the basic metal sector.

With regard to company size, 53% of all companies were in the range of 51 to 250 employees (Fig. 18). Only Spain had a focus on smaller companies with 71% in the range of up to 50 employees.

**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, and 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.  

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 (Fig. 19).

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.

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26 For details of the SAT please see the REMake project website: www.ecomanufacturing.eu
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. 23) over the last three years. Many companies have already addressed waste reduction, material efficiency, energy efficiency and recycling at least to some extent. (It should be noted that the relatively high scores in this overall question could be misleading when analysed in more detail, please compare issues further below). 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. 23: Resource efficiency measures already implemented by the companies assessed](image)

Scrap or defective parts are caused by …

![Fig. 24: Reasons for scrap production](image)

Fig. 24 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 (70%), whereas only 42% of Italian companies see this as a major cause of problems. In Italy set-up and ramp-up processes are regarded as more critical (62%).

By far the majority (80%) of the SMEs in the sample undertake measures to reduce scrap on a regular basis or at least sometimes. UK companies of the sample pay particularly high attention to this issue (Fig. 25).

Also scrap recycling is done by 80% of the companies in the sample, yet mainly off-site by specialised third parties (Fig. 26). The shares in different countries are very similar except Italy with higher share of internal recycling.

While human error is seen as a relevant cause of inefficiencies, most companies are satisfied with the way their employees are dealing with failures: Only 4% say they do not detect failures during production and another 5% say employees would detect a failure but would not react. 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 rely only on an introduction 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. With 29% German companies are putting significantly more effort on specialist training while French companies have the lowest score in this field (7%).

Astonishingly, a rather high share of companies have no idea of their energy consumption (24%) or only know their overall energy use but are not monitoring the energy consumption of their processes (31%). This is in stark contrast to Fig. 23 where most companies stated they were undertaking measures to improve resource efficiency in many ways. In UK even 38% of companies stated they have no knowledge of their energy consumption, whereas in Spain 54% know only their overall energy use. Only 16% of all companies have a detailed knowledge of the energy consumption of individual processes. 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.

Water saving is relevant for 60% of all companies in the sample, while in Germany 62% and in UK 56% of companies state that water saving measures are not relevant due to low water consumption. 50% of companies apply measures to save or recycle water systematically or partially. A higher share of 62% is achieved in France, whereas only 32% of German companies confirm regular water saving measures.

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 while in Germany, 24% of companies state that they do not undertake such improvements.

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 (18%). 12% of companies do not consider environmental or efficiency issues during product development, in Spain this share is even 44%.

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%). A smaller number of companies intend to use materials sourced locally (28%) or use only materials from companies with Environmental Management Systems. 15% of the companies do not take aspects related to materials efficiency and environment into account; in Spain, this share is 44%.
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. Some inefficiencies in the management field are related to the following areas:

Many companies state that insufficient cooperation between operational units of the company or between individual employees is sometimes (55%) or regularly (9%) causing inefficiencies (Fig. 34).

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. EMS in particular scores highest in UK (68%) and lowest in Spain (24%), see Fig. 36.
Purchasing, storage, packaging, distribution

64% of companies have to dispose of raw materials or finished products directly from stock sometimes or even regularly. Since this is similar in all countries, a critical issue would be to improve stock keeping and stock handling in SMEs.

Failures do also arise due to purchasing, such as missing parts causing interruption of production flow in 76% of the companies sometimes or regularly. Only 23% of companies state no failures due to missing parts.

Also handling and transport is a significant cause of failure leading to scrap or reworking.
because of materials or products damaged during handling within the company or during transport to the customer. Only 26% of companies within the sample state that such damages never happen.

A final cause of inefficiencies enquired are related to potential bottlenecks between distribution and production. These could be caused by different issues: Incorrect sales forecasts (37%), incomplete information exchange between operation units e.g. concerning delivery deadlines or production volumes (37%), unclear delivery dates (35%) and other reasons. For only 18% of companies this is not applicable. In Germany unclear delivery dates and “other reasons” play a major role, whereas in UK incomplete information is a higher bottleneck.
Evaluation of resource saving potentials of two exemplary manufacturing value chains

Pre-selection of typical manufacturing value chains as a basis for analysis

Various studies have already identified resource intensive sectors. According to a recent UNEP report\textsuperscript{27}, buildings and construction industry, agriculture and food, and metals and manufacturing are most resource intensive industries with considerable impact on resource use and the environment. Similar results can be found for material efficiency of German industries (Table 13\textsuperscript{28}). The same study identified also the saving potential of different sectors as shown in Table 14.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
& in m t & in % \\
\hline
Construction & 964 & 18 \\
Food and feed stuff & 465 & 9 \\
Metal products and semi-finished products & 459 & 9 \\
Machines & 211 & 4 \\
Automotive and automotive parts & 335 & 6 \\
Energy and related services & 405 & 8 \\
Chemical products & 269 & 5 \\
Others & 2,181 & 42 \\
\hline
Total & 5,289 & 100 \\
\hline
\end{tabular}
\caption{Resource use in different sectors (H. Rohm et. al. (2008))}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
& in bn EUR & \\
\hline
Construction & 11.1 & 0.2-1.2 \\
Production of metal products & 18.6 & 0.8-1.5 \\
Production of plastics products & 10.8 & 1.0-2.0 \\
Production of electricity generation and distribution devices & 10.2 & 1.5-3.0 \\
Chemical industry (w/o basic substances) & 11.1 & 1.8-3.4 \\
\hline
Total & 61.8 & 5.3 – 11.1 \\
\hline
\end{tabular}
\caption{Relevance of industrial sectors and resource savings potentials (H. Rohm et. al. 2008)}
\end{table}

The study by K. Rademaekers\textsuperscript{29} identified in a similar way nine resource intensive sectors and their resource efficiency potential: food and drinks, cement, non-ferrous metals, electronics, chemicals, automotive, steel, glass and finally pulp and paper, based on a value chain perspective; thus examining the value added to materials starting from their extraction (at the raw material stage) to their disposal (waste). The selection of the nine sectors in this study was based on two criteria: 1) their high dependence on resources in their production, 2) the potentially high impact they may have on the environment through their daily operations.

The study by R. Baron\textsuperscript{30} identified for Germany the highest savings potentials in the following

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\textsuperscript{27} UNEP (2010)
\textsuperscript{28} See for example H. Rohm et. al. (2008),
\textsuperscript{29} K. Rademaekers et. al. (2011)
\textsuperscript{30} R. Baron et. al. (2005)
Potential resource efficiency savings of the manufacturing industry – Final Report (December 2012)

sectors: Production of metal and plastics products, including coated parts, production of devices for electricity generation and distribution as well as production of chemical products. According to these data, the following sectors were of interest for further analysis:

- Production of metal products, including coated parts;
- Production of plastics products, including coated parts;
- Production of devices for electricity generation and distribution;
- Production of chemical products;
- Construction;
- Food and feed stuff production.

Based on further discussion with industrial partners and R&D institutes, the following sectors have been selected for further analysis of exemplary production chains in this study:

- Metal production including coatings;
- Plastics processing;
- Food production.

These three sectors are characterised by a high resource use and a high savings potential as highlighted above, but have very different characteristics concerning materials, production chains etc.. They are hereafter described in more detail.

**Process chain 1: Production of metal products**

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. 41).

![Fig. 41: Process chain metal forming / coating](image)

Each of the three main steps consists of a number of subsequent or alternative sub-chains, depending on the specific product design and functionalities to be achieved. Additionally, the following processes are linked to these main processes: product development, transport and storage, handling, cleaning, waste and waste water treatment etc. 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. Better integration of the overall production chain, and in particular a better integration of surface engineering with preceding manufacturing steps, will lead to substantial advances in overall process efficiency and sustainability.

As a typical production chain for one example of this study, the production of stainless steel hydraulic pistons with hard chromium coating has been selected. Such parts are highly relevant components for example in construction machines. The following aspects have to be
considered for this production chain:

1) **Steel**

The ongoing trend of an increasing worldwide demand for steel has strong impacts for the producers of steel products. The prices for steel but also for steel scrap have been increasing significantly. The increasing worldwide competition contributed, for instance, to an increasing orientation by German steel producers towards high quality and more customer specific products to remain competitive; additionally resource efficiency measures like reduction of material input e.g. by zero loss management, a more resource efficient product design or forming processes, have partially already been implemented. But in order to increase resource productivity significantly single step optimisation is not sufficient in this sector: systematic improvements along the whole production chain and an optimised product design minimizing steel use (e.g. innovative materials, geometry, light weight construction) would be needed.\(^{31}\)

2) **Electroplating**

Electroplating of hard chromium coatings is a very resource intensive process, with high potential for improvements. Overall optimisation of the production chain will be essential for improving resource efficiency in electroplating. This should consider both further technology development to improve the resource efficiency of the manufacturing chain for the functional coating (e.g. hard chrome) and the potential use of alternative coating processes depending on application areas. Alternative technologies in different process stages could include:

- Alternative pre-treatment processes for metal parts like alternative mechanical processes in forging and casting parts (e.g. vibratory, blasting) or adaptation of the pickling process taking into account the metallic substrate type, using different acids, or using atmospheric plasma where possible;
- Closed loops of chromic acid and filtering of processing solutions, recycling of chrome with a membrane electrolysis, heat management systems for plating equipment;
- Reduction of carry over losses by optimised racks, optimised product geometry, optimised rinsing systems with water quality measurement;
- Integrated (and fully encapsulated) production technologies for chrome coating allows for optimisation of the whole production process regarding chrome and energy consumption;
- Recycling, i.e. external recycling of galvanic sludges or internal recycling of primary materials from concentrates and rinsing water.

**Process chain 2: Production of plastics products**

In the manufacturing of plastic products the share of material cost in overall production costs

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\(^{31}\) T. Lemken et.al. (2009); K. Rademaekers et. al (2011)
equals 40% or above. The core steps of plastic part production are material pre-treatment and melting, forming as well as ejecting and post-treatment as shown in Fig. 42.

Main production processes for forming 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 product design, material handling and storage, and other processes like waste, waste water or exhaust air treatment. Moreover the plastics part may be coated, too.

Opportunities for increasing the material efficiency in plastic products manufacturing are mainly given in product design and process development:

- Intelligent eco-efficient product design ("design-to-cost", see further below) with lightweight structures and use of innovative plastic compound materials (e.g. fibre reinforcement with lightweight textile fibres).
- Substitution of presently used plastic materials by more advanced, light weight materials.
- Development of efficient product specific production processes ("zero loss management")

The optimisation of existing processes, on the other hand, has only a limited potential for further material savings. Also recycling of production wastes can only be further increased to a limited extent.

**Process chain 3: Food production**

Studies by the European Commission\(^\text{32}\) estimate food waste within the food & drink manufacturing process chain at almost 35 mt per year in EU27; this represents some 39% of EU total food waste, based on the available data collated by EUROSTAT from across the member states.

Studies in the UK have indicated that there are significant resource efficiency savings possible within the UK food and drink manufacturing sector. Studies produced by WRAP in 2010 estimated the waste arising from the sector at some 5 million tonnes per annum, with a further 2.2 million tonnes of by-products being sent for animal feed.

A more recent WRAP report\(^\text{33}\) drilled down further, quantifying actual food and packaging waste generated at a number of example manufacturing sites. By extrapolating these results across the sector it was calculated that the potential achievable annual waste reduction across the UK food and drink manufacturing sector stood at some 720,000 tonnes, with a savings value estimated at £404 million.

The DG ENV report identified that the main causes of waste generation differ at the various steps in the food cycle from farm to fork, and suggests that the key areas to focus on for the

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\(^\text{32}\) e.g. EC DG ENV (2010)
\(^\text{33}\) WRAP (2011)
Manufacturing and Processing stage would be packaging, logistics, product quality and technical malfunctions.

WRAP’s research generally compliments these findings and proposes lean manufacturing principles as an approach to realise appreciable savings without recourse to major re-engineering of existing processes. The various ‘types’ of lean waste can mostly be directly mapped to the main causes of food waste at the Manufacturing & Processing stage identified in Fig. 44.

1. Overproduction – manufacturing product for which there are no orders
2. Inventory – excess raw materials, work-in-progress or finished products
3. Defects – production of off-specification products that result in rework or rejection
4. Transportation – excess transport of work-in-progress or finished goods
5. Over processing – process steps that are not required to produce the product
6. Waiting – delays associated with material shortages, equipment downtime or capacity bottlenecks.

Example food processing chain; Cereal Products
- Sourcing of raw materials from agricultural suppliers;
- Quality measurement;
- Raw ingredient dosing and dry mixing;
- Cooking; ingredients are cooked with steam pressure;
- Milling; moist product passes through rotating mills to form pellets;
- Drying; pellets pass through multi-stage dryer to remove moisture;
- Tempering; develops colour and flavour;
- Flaking; pellets forced through two rotating mills to produce final shaped flake;
- Toasting; flakes rapid dried by passing through high-temperature oven;
- Packing;
- Distribution.

Final selection based on availability of actual data and industry support

Despite significant efforts invested in convincing companies of the benefits of participation to the present study, the necessary hands-on industrial collaboration could only be gained from companies of two manufacturing chains in the metal and plastics production sectors:
1) "Steel" manufacturing chain: the example of producing hydraulic piston rods for construction machines and other large hydraulic equipment;

2) "Plastics" manufacturing chain: the example of mass producing of plastic housings for household appliances such as electric kettles, electric irons, and other similar equipment.

These two manufacturing chains have been simulated in terms of their resource flows using a proprietary life-cycle simulation software of subcontractor LCS Life Cycle Simulations GmbH. The simulations have been performed based on data for resource input, wastes and production output received from collaborating companies. In both cases one company in the manufacturing chain was the main contact and supporter through which the data acquisition over the rest of the value chain was organised. Where appropriate, the simulation was simplified if generalised data were available from according databases (e.g. for resource use of basic processes such as ore extraction which is the same for all steel production and hence did not need to be investigated for the specific case).

In the food & drink industry despite an original interest and commitment of an innovative medium sized company to participate in the study, the required support from the company for the actual data acquisition could not be received within the timelines of the study.

**Resource savings potential of a metal mechanical manufacturing chain for hydraulic piston rods**

Hydraulic piston rods are widely used in machinery such as lifting devices, material handling equipment and construction machines. The manufacturing chain is a typical example for metal mechanical production since it includes all steps from sophisticated steel making, precision machining and functional coating to obtain maximum corrosion protection and hardness as well as a flawless surface ensuring optimal functionality of the machinery.

The life cycle simulation has been carried out based on two different scenarios, a “best” case scenario and a “conventional” or worst case scenario for the production of hydraulic piston rods used in diggers. An important differentiator between the two cases was using low quality steel in the conventional case scenario or a high quality steel in the best case scenario as point of departure. The manufacturing chain included the following production steps and system boundaries:

- Steel manufacturing of piston rod from steel;
- Surface processing and corrosion protection;
- Packaging for transport;
- Heat degreasing;
- Hard chromium plating;
- Finishing;
- Recycling processes and heat recovery.

The following processes could be neglected or are the same for both scenarios and therefore did not need be considered:

- Steel casting is the same for the conventional and best case scenario (the higher quality being produced through subsequent treatment);
- Stretch levelling can be neglected because of subordinate relevance;
- Transport costs are not considered because they do not differ for the scenarios;
The use phase is not considered for the piston rod, because it doesn’t differ for the scenarios; Welding is not considered because of subordinate relevance.

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).

![Diagram of processes and resources of the conventional case scenario](Image)

The two manufacturing scenarios are illustrated below in more detail.

1) The conventional case scenario is depicted in the following graphic (Fig. 46):
2) The best case scenario is shown in Fig.47:

The simulation results for the basic steel part of a hydraulic piston rod (before hard chrome plating) are shown in the mass balance in Fig. 48. Savings in subsequent production steps are not considered. The mass balance of the steel part shows that using higher quality steel in the “best case” scenario avoids significant amounts of scrap (chips) in surface treatment, i.e. the required surface quality can be achieved with less effort. Thus the overall steel demand can be minimized.

Fig. 47: Processes and resources of the best case scenario

Fig. 48: Simulation results: Mass balance for the basic steel part

As Figs. 49a and 49b show, the difference between best case and conventional case scenario accounts together to 1,582 MJ per product corresponding 38 kg raw oil equivalent. This corresponds to a saving of 55% compared to the primary energy use of the conventional
case scenario. Slightly higher burdens in the best case scenario in the steel production step result in significant savings in subsequent steps.

The analysis of primary energy use in Fig. 49a and 49b for different production stages shows:

- The higher energy used to produce the increased steel quality in the best case is counterbalanced by the higher materials use of the conventional case part. This higher
material use is only due to a higher amount of scrap metal which needs to be removed from the lower quality steel part before precision machining and coating;

- Even with significant removal of scrap metal in the conventional case scenario, the improved steel quality in the best case scenario leads to significant savings in subsequent manufacturing steps finishing, degreasing, and in particular in hard chromium plating. This is due to the fact that blowholes in the surface of the conventional steel cause significant problems in chromium plating which lead to a high amount of rejects;
- Welding, corrosion protection for transport and transport can be neglected.

**Effect of manufacturing chain optimisation without internal optimisation at the coating factory**

The best case scenario includes an optimised hard chromium plating process which could be implemented independent of the value chain optimisation, by applying best available technology (e.g. form anodes, insulating cover plates, heat recovery, etc.).

In order to identify the improvement potential caused only by the value chain optimisation, a simplified best case scenario was analysed applying the same standard hard chromium plating process as in the conventional case scenario, i.e. without considering internal process optimisation at the hard chromium plating factory.

![Fig. 50: Primary energy use (in MJ) without individual optimisation of chrome plating](image)

The results also for this simplified best case scenario – considering only savings influenced by interface optimisation across the value chain – are striking: even though the individual process optimisation at chrome plating factory can cut energy consumption by one third, the value chain optimisation still has a much larger effect, reducing the energy consumption at
the chrome plating to only 10% of the conventional case and cutting the total energy consumption over the value chain by half.

The total difference between the simplified best case scenario and the best case scenario with internal factory optimisation is about 7% which is well in the order of factory level process optimisation per product output identified in the analysis of the savings potentials of individual companies.

Effects of reducing the assumed reject in the simulation

The basic scenario had used a reject rate at the coating process of 80% in the conventional case due to the conventional steel quality, and 5% in the best case scenario (according to information provided by the chromium plating company). In this case the primary energy use of the worst case scenario is 122% higher than in the best case scenario (by utilising all saving potentials). Even a reduction of the reject rate to 40% still shows significant saving potential compared to the best case scenario.

Absolute savings potential in this particular case:

With about 120,000 hydraulic piston rods jointly produced per year by the companies investigated, the total energy saving across the analysed value chain is in the order of 4,500 tons of oil equivalent.

While in this example the total energy savings are more significant than the materials savings, the energy saving is highly dependent on how the material resources are used. Moreover, the material savings are also substantial and reach up to 10% of the steel use of the conventional case.
Evaluation of a plastic product manufacturing chain

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 in the conventional case scenario assumes an injection moulded and then varnished plastic housing whereas in the best case scenario the housing is produced by film back moulding. The processing steps are illustrated in Fig52.

As the mass balance in Fig. 53 shows, choosing a more advanced and complex production technology in the core plastics processing allows for higher material efficiency in the overall manufacturing value chain. One key issue is that more complex structures with holes and

![Diagram of processing steps](image)

![Graph of mass balance](image)
notches can directly be fabricated, hence reducing subsequent cutting processes to a minimum which otherwise would produce substantial cutting wastes (scrap). The best case scenario therefore requires significantly less granulate as Fig. 53 clearly shows (though depicting only the production of the structural plastic component before painting / without cover film).

Besides this direct reduction of material use, film back injection moulding has much 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 for painted plastic products a significant amount of the granulate can come from recycled plastic.

Moreover, the painting process can be completely avoided and with it substantial energy consumption which is necessary for drying as well as material loss due to overspray in the painting process (typical 30% of varnish / paint is lost through overspray).

In Fig. 54 and Fig. 55 the total resource consumption over the value chain is integrated and calculated as primary energy use (since the plastic materials can easily be translated into oil equivalent). The result is as significant as for the metal mechanical case study: through changing the value chain a total savings 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 of film back injection moulding allows material savings (15%);
- The process allows to use recycled plastics (10% for a recycling rate of 25%);
- By avoiding the painting process the overall reject rate is also reduced (2-3%).

Fig. 54: Primary energy balance of the plastic housing (1)
Conclusions

Like many industrial technology fields, eco-efficiency is developing waves: while in the beginnings industry and policy have relied mainly on so-called ‘end-of-pipe’ measures; cleaning wastewater and air, recycling, and continuous improvements in energy efficiency, the focus has shifted to the supply of energy and raw materials which is increasingly under pressure. Accordingly, enhanced efficiency in resource use and in prevention, re-use and recycling of valuable raw materials from waste streams, with a specific focus on materials that have a potentially negative impact on the environment is high on the agenda.

R&D efforts have been targeted on this area for more than a decade and first 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.

In this context the present study is arguing for a next ‘wave’ of eco-innovation to be prepared, addressing resource efficiency optimisation of whole manufacturing value chains instead of isolated single company / single process level 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.

The analysis of company level resource efficiency optimisation under the German Materials Efficiency Programme showed an average resource saving potential of about 7 – 10% of material input (total resource savings about 10 – 15%). Even though the case studies have been very heterogeneous with very substantial resource savings of 20% and beyond in individual cases, the majority of companies show a savings potential between 4 – 8%. Smaller companies tend to achieve higher average relative material savings than companies with higher turnover for which the savings potential can even go down to 2%.

It had been estimated (preparatory study for the Germany Materials Efficiency Programme) that overall savings to be achieved just by applying best available technologies could already
reach up to 20% of total abiotic resource consumption while process optimisation at individual company level – as analysed in the cases studies - typically reaches only up to 10% of the firms’ resource consumption.

The cases with high savings potential would clearly need further investigation, to explore the reasons behind these savings (e.g. lack of improvement over a long time vs manufacturing organisation breakthrough), but a very obvious issue arising from this analysis is the strong connection in technical terms between materials and energy use and related savings potential. This is clearly pointing to the fact that separated energy or raw materials efficiency programmes are 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. This has also been documented in a study by Fraunhofer Institute IAO in 2010. While the relevance of resource efficiency is regarded as high by most of the companies, simple short term measures are generally preferred even if the savings potential addressed is comparably lower. This is consistent with findings in the case study analysis that most investments made for resource efficiency improvement pay back within only one year, and definitely less than 2 years. 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 the nature of their funding are typically required to generate measureable economic results within a fairly short timeframe – three years from start to close being a typical funding duration for a business support programme in the UK. 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 actual measures that have been implemented in the case studies to improve resource efficiency were focused mostly on 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 supply chain or overall value chain optimisation is not used by companies; hence a quite significant saving potential is still being neglected.

This has been demonstrated through the analysis of the two exemplary manufacturing value chains of a typical metal mechanical production and typical mass production of plastics products. Both value chain simulations have shown resource savings potentials which are by an order of magnitude higher than those of single process or factory level improvements.

- The life-cycle simulation of the hydraulic piston rod value chain has for instance clearly
shown that producing high quality steel requires more effort but results in important savings at the level of surface treatment where the production process can be optimised and a significant amount of scrap is avoided, thus minimising the overall steel demand. For each hydraulic piston rod, the total primary energy demand can be reduced by 1,582 MJ which corresponds to 38kg of crude oil, i.e. savings of about 55% primary energy use in the best case compared to the conventional case scenario. Further, all individual impact indicators considered also show significant saving potential.

Very importantly, the scenario excluding single company level optimisation showed a savings potential which was only 6% lower than the best case scenario including factory level optimisation. This strongly supports the assumption that value chain optimisation could be substantially (order of magnitude) higher than factory level improvement. Moreover, at least in this particular case, factory level optimisation is not included in the value chain optimisation but adds up to the total savings achieved in the best case scenario.

- The best case scenario of the plastics product value chain exhibited an even higher savings potential of up to 70% of primary energy use (the figure includes raw materials savings translated into oil equivalent). This is particularly due to the fact that both significant energy and raw materials savings could be achieved. On the other hand, single factory measures (e.g. on the painting or drying processes) in this case would not add up to total savings since these processes are completely replaced by the technology change in the manufacturing value chain.

As results indicate, the two examples of resource efficiency optimisation across manufacturing value chains exhibit much higher saving potentials than (the sum of) single process / factory improvements. Together with the fact that both value chains had been selected based on their industrial relevance as typical examples of the manufacturing processes in these sectors, this well supports the assumption that value chain optimisation could be a very effective lever to improve resource efficiency in addition to single company improvements.

Nevertheless, both will be required 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 detail in the course of the REMake project\textsuperscript{34}; from this analysis the most relevant reasons for this specific decision behaviour are still:

- 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;

\textsuperscript{34} 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.
**Insufficient incentive to invest** in resource efficient technology due to the complexity of integrating new technology into existing processes.

One additional aspect which has clearly come out of the analysis 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.

In terms of **policy recommendations**, what is most important is still a better understanding of resource efficiency. In this respect it is critical, for instance, to understand that the four dimensions to ‘resources’ – i.e. raw materials, energy, supplies and wastes – are equally important since they are strongly interlinked across the value chain of a product, requiring integrated optimisation to get optimal results.

A further relevant issue is to address resource efficiency at the three principle levels of innovation:

1. **Resource efficient manufacturing and recycling processes at single factory level** 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** across the various interfaces (i.e. between factories) of the complex manufacturing **value chains**, including waste recovery and recycling / re-use.

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

To allow a better understanding of the pressures and benefits around resource efficiency in the UK, 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.
Literature

- R. Baron, et.al. (2005): „Studie zur Konzeption eines Programms für die Steigerung der Materialeffizienz in mittelständischen Unternehmen“, Abschlussbericht
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- Eurobarometer (2011): “Attitudes of Europeans to Resource Efficiency”
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- K. Kristof, P. Hennicke et. al (2010): “Endbericht des Projekts “Materialeffizienz und Ressourcenschonung” (MaRess)“, Projekt i. A. des BMU / UBA, Wuppertal
- Lowell Centre For Sustainable Production (2009): “A New Way of Thinking”


ANNEX 1: Technical measures to improve the resource efficiency of manufacturing SMEs

This annex gives a short overview on exemplary generic, cross-sectional technologies and approaches to improve resource efficiency which could be applied throughout any production chain. For sector specific solutions on the other hand, the IPPC BREF documents are the most relevant source of information.

Yet, since the BREF are difficult to analyse for people who are not a sector expert, most studies have focused on analysis of the impacts of generic, cross-sectoral technologies.35 “Cross sectoral” means technologies to increase resource efficiency (including material substitution), which can be applied in different (but not necessarily in all) sectors in a comparable way. According to these studies, most important cross-sectoral technologies are the following:

**Measures for factory level improvement of manufacturing resource efficiency**

**Basic approaches:**
- Reducing resource losses and production wastes by improving process reliability and decreasing cuttings and rejects;
- Reducing the use of operating fluids and supplies, including water;
- Recycling of production wastes and waste water e.g. separation techniques for complex feedstock;
- Water management: e.g. membrane technologies for specific applications, closed water cycles;
- Minimising tool wear by using advanced tool materials;
- Improvement of cleaning and conditioning processes;
- Efficient electric motors, pumps, compressed air generators (e.g. through variable speed drives);
- Optimised operating parameters to improve capacity utilisation of machines and plants, optimisation of assembling processes;
- Improved storage and logistics.

**More advanced approaches:**
- Use of renewable resources, including renewable raw materials such as recycled or bio-based plastics;
- Renewable energy sources, advanced energy storage, heating and cooling technologies;
- New functional materials and materials for light weight structures;
- Implementing improved process control and inline-inspection systems with pre-processing prognosis;
- New technologies for drying (e.g. IR drying) and cleaning (e.g. by vibration) processes which use less energy and supplies;

35 Compare for example S. Behrendt, L. Erdmann (2010); R. Baron et.al. (2005) or H. Rohn et. al (2008)
- Implementing near-net-shaped manufacturing concepts in particular for steel;
- Near zero-waste concepts through advanced recovery, remanufacturing and recycling;
- Process intensification: e.g. micro reaction and micro process technology, new technologies for catalysis, coupling of existing processes with biotechnological processes;
- New production strategies and consumption patterns such as production on demand, self organised production processes, new product-service systems in the use phase (e.g. refurbishing, contracting);
- Functionalised surfaces (nanotechnologies), optimised tribological systems, new coating technologies.

**Resource efficient product design**
- Improved product use properties, such as life-time, recyclability etc.;
- Consideration of resource efficiency criteria for product dimensions and geometry already at the design stage;
- Design for reuse (i.e. remanufacturing and recycling);
- Optimised materials and materials technologies such as light weight construction, use of renewable materials, tailored materials properties, use of bionics principles;
- Design for resource efficient manufacturing.

**Measures at supply chain level**
- Optimising transport processes, storage and packaging (including packaging material);
- Integrated manufacturing optimisation along the value chain.

Please find hereafter further elaborations on some key issues of the above list.

**Reduction of water consumption**

Despite many regulations at Member State level concerning the use of fresh water, waste water disposal and water recycling requirements, there is still a significant potential for improving the efficient use of water, in particular within industrial SMEs.

In particular with regard to waste water recycling, new process developments aim to replace chemical waste water treatment by physical processes which would especially reduce the amount of sludges.

A reduction of fresh water consumption can be achieved through the use of rain water or ‘grey water’ as well as through closed water cycles for cooling water and other process waters. For the latter, process wastes contained in the waste water streams need to be filtered out and can eventually be fed back into production processes.

**Improved tribological properties**

Knowledge of tribology – addressing all issues related to friction, wear and lubrication - had been substantially advanced over the past decade through the availability of many new sophisticated measurement techniques. The application of this knowledge leads to reduced friction and wear, and overall to an increased operational safety and efficiency of machines and production equipment.

Concrete opportunities for increasing material efficiency through application of tribological
knowledge, often in combination with new materials, include for instance:

- Significant increase in tool lifetime for metal working, combined with minimised lubrication needs (as an example, the total cost related to lubrication are estimated at 20% of all metal working costs in car manufacturing);
- The lifetime of bearings in machines and process plants can be substantially increased, and at much higher rotation speeds. This leads to increased availability and efficiency.

**Substitution of conventional materials**

Advanced material development is focused on meeting holistic requirements, starting from specific application needs but integrating as well all aspects of processibility, optimal material efficiency, recycling and energy consumption over lifetime. Such combination of material, mechanical engineering and design innovations then lead to systematically optimised products.

In this context, priorities for material development are in tailored composite materials with metals, ceramics, compounds, sandwich structures and functional coatings, combined with appropriate production processes.

**Tailored product properties based on new efficient processes**

To maintain their competitiveness, producing enterprises must be capable of producing products with tailored functionalities that meet the requirements in terms of an increased performance and product lifetime without reducing functional reliability. Generation and adjustment of product properties by innovative manufacturing technologies are aimed at increasing the power density of the component and, at the same time, at reducing the consumption of material as well as at increasing functional variety and reliability in the product lifecycle.

**Advanced manufacturing using bionic principles**

One example is the so called vault structuring of metal or plastic sheets.

Vault Structuring uses a material’s self-organisation response to a very gentle and sustainable force to create a perfectly staggered three dimensional honeycomb structure (compare image below).

The process differs greatly from the traditional mechanical embossing and stamping technologies. The naturally occurring three-dimensional honeycomb structure shows typical properties of a self-organized process. The most important result of the process is an increased stiffness combined with a low weight at greatly reduced materials and energy input.

Concrete applications include:

- metal cylinders or cylindrical containers of various materials (metal, plastic, paper) with substantially reduced wall thickness at the same stiffness e. g. for liquid containers;
- light weight structural components in automotive design;
- light weight washing machine drum (Miele);
- light weight, self-supporting reflectors for lamps.
ANNEX 2: Related Case Studies Undertaken within the REMake Project

Process Efficiency in a German Electroplating Business

A REMake resource efficiency consulting was performed in an electroplating job-shop with about 30 employees and turnover of roughly 2 million Euro. The company offers a large variety of decorative and functional metallic coatings, the latter in particular for corrosion protection, on steel, aluminium and other non-ferrous metals. The broad product range includes chromium, chemical nickel, galvanic nickel, tin, silver and zinc coatings with yellow, blue, olive and black chromate conversion coating. Also the product spectrum to be coated is very broad with many different product geometries and product sizes.

In the company which was founded at the end of the 1990s only little had been done before to close process cycles and reuse materials and process supplies. Consumption of materials and process supplies including water and waste water streams was accordingly quite high.

The consulting case was performed in the context of the resource efficiency initiative of the German electroplating industry initiated within REMake. The process optimisation undertaken in this consulting case focused on the following measures:

- Recycling of dragged-out electrolyte into electroplating baths before dilution with other agents;
- Increased bath stability and bath use time control of bath parameters;
- Reduction of rinsing water consumption through advanced rinsing technique;
- Reduction of water evaporation;
- Reduction of waste materials, in particular sludges;
- Reduction of waste water.

As a result, the following savings could be achieved: 8% reduction in chemicals used; 16% reduction in fresh water supply; 20% reduction of water evaporation (with according energy savings); and 8% reduction of anode metals used.

Quantitative description

Before optimisation:

- Production output: approx. 50,000 m²/a (coated product surface)
- Relevant materials input:
  - Chemicals consumption approx. 66,800 kg/a 76,500 €/a
  - Fresh water consumption approx. 12,500 m³/a 23,000 €/a
  - Anode metals approx. 3,000 kg/a 52,800 €/a
  - Total costs of materials / supplies 152,300 €/a
  - Electrical energy approx. 4,400 GJ/a 78,000 €/a
  - Waste water approx. 10,500 m³/a
    - Waste water disposal 20,200 €/a
    - Chemicals for waste water cleaning 17,900 €/a
  - Galvanic sludges 12,000 kg/a 3,700 €/a
  - Solid waste 16,950 kg/a 4,500 €/a
  - Water evaporation 2,100 m³/a
Annual savings in materials / supplies after optimisation:

<table>
<thead>
<tr>
<th>Material</th>
<th>Annual Quantity</th>
<th>Annual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemicals</td>
<td>3,000 kg/a</td>
<td>10,000 €/a</td>
</tr>
<tr>
<td>Fresh water</td>
<td>2,000 m³/a</td>
<td>7,500 €/a</td>
</tr>
<tr>
<td>Anode metals</td>
<td>250 kg/a</td>
<td>4,500 €/a</td>
</tr>
<tr>
<td>Waste water treatment</td>
<td>1,250 m³/a</td>
<td>18,500 €/a</td>
</tr>
<tr>
<td>Solid wastes</td>
<td>2,840 kg/a</td>
<td>1,000 €/a</td>
</tr>
<tr>
<td>Evaporation losses</td>
<td>640 m³/a</td>
<td>25,000 €/a</td>
</tr>
</tbody>
</table>

( equivalent to about 1,400 GJ when calculated only for cleaning & post-treatment baths with no heating through electric current)

Total annual cost savings:

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost saving / materials</td>
<td>22,000 € (14%)</td>
</tr>
<tr>
<td>Cost saving / waste water</td>
<td>18,500 €</td>
</tr>
<tr>
<td>Cost saving / electr. energy</td>
<td>25,000 €</td>
</tr>
<tr>
<td>Total annual cost savings</td>
<td>65,500 €</td>
</tr>
</tbody>
</table>

In relation to the company’s turnover of 2 million Euros this is equivalent to 3.3% of total annual turnover. Assuming a profit margin on turnover of about 6% before optimisation, a **profit increase of over 50%** could be achieved.

Investments required for the implementation of resource saving measures:

- Additional rinsing baths
- Tensiometer to measure surface tension as a key parameter for bath control
- Redesign of exhaust airfunnels
- Redesign of piping
- Coupling of valves to the process control system
- Cover system for electrolyte baths

Total one-off investment costs about 10,000 € for installation plus consulting costs of about 25,000 € for analysis of optimisation.

Payback time including consultant fees about 6 months.
Trak-Rap case by C-Tech Innovation

SME Identification

Trak-Rap is a limited company, founded by WT Johnson & Sons Ltd, which has a history in designing and developing innovative technology. Trak-Rap's technology extends to packaging and 15 years ago they undertook a research programme to find an alternative to the use of heat tunnels in the packaging process. Their products aim to provide an alternative to traditional packaging solutions with the intention of reducing energy intensity, material use and increase recyclability. This in turn reduces the carbon footprint of the materials in order to meet demands from Supermarkets for Retail Ready Packaging.

Lower Cost, More Environmentally Friendly, Packaging

• Trak-Rap's new "Lightweight, Cold Film, Technology"
• Reduced energy use, film weights and cardboard weight
• Lower Environmental footprint established by CcaLC Carbon Footprinting Tool.

Challenges:
The usual aim of product carbon footprinting is to reduce GHG emissions; however, organisations may have specific goals within that overall aim. This process provides many challenges such as:

• Enabling effective product selection to generate more useful findings at the end of the assessment
• Gaining direction on the scope, boundaries and data to be used in calculating the footprint
• Making an informed decision and verification of data quality

This in turn raised the following questions:

• What product to select?
• Who are likely to be the key supplier contacts?
• What resources and budget can be given to the project?
• What governance/ decision making structure will guide the project?
• How long will it take?
• Who is responsible for what, and what will they deliver?
To answer these questions a process map was developed until all inputs had been traced back their original sources, and all outputs tracked until they stop emitting GHGs attributed to the product. This process subsequently took multiple attempts.

### Methodology

**Initial research:** C-Tech Innovation sought a suitable company to be involved as the REMake Case Study. Following Trak-Rap’s involvement in the North West Eco Innovation Programme it was thought to be mutually beneficial to trial CCaLC\(^{36}\) as part of the REMake programme.

**Initial Face-To-Face Meeting:** An initial meeting was held on the 31.01.2011 with Martin Leeming of Trak-Rap to discuss REMake and CCaLC and its capabilities. Initial data requirements and suitable case study examples where identified for further development.

**Data Collection:** During February, C-Tech Innovation collected data via the use of a data inventory to gather required information for CCaLC to be used to capacity. Trak-Rap contacted their supply chain to verify information and confirm boundaries for data collection.

**Data Input:** The data collected was inputted to the CCaLC tool, the results where then analysed by C-Tech Innovation. The calculations and data were placed into report format to be presented to Trak Rap.

**Final Meeting Face-To-Face Meeting:** A presentation of the results as well as details on how the tool can be downloaded and a copy of the user manual. C-Tech also advised on how this information may be used by Trak-Rap:

- Reduce Green House Gas (GHG) emissions
- Identify cost saving opportunities
- Incorporate emissions impact into decision making on suppliers, materials, product design, manufacturing process etc.
- Demonstrate environmental/corporate responsibility
- Meet customer demands for information on product carbon footprints
- Differentiate and meet demands from ‘green’ consumers

Furthermore analysing the life cycle of a product creates common metrics that can be compared and shared across the company, with suppliers and partners.

### Main benefits for the SME

**Client Feedback: Martin Leeming**

‘Working alongside C-Tech Innovation on the REMake programme to test the CCaLC carbon foot printing tool has been very beneficial to Trak-Rap. Our new innovation is aimed directly at bringing lower cost, more environmentally friendly and, retail ready packaging to the

\(^{36}\) CCaLC is publicly available tool for calculating environmental and economic impacts of life-cycle carbon inventories; see http://www.ccalc.org.uk
Supermarkets. Using the CCaLC tool we were able to simplify a very complex area and verify the environmental benefit of replacing cardboard and shrink film with our new "cold film" technology. This, in turn, allowed us to align our strategy to the Courtauld 2 agreement that underpins the industry's efforts to reduce their Carbon Footprint. So far, using the tool, we have reduced the carbon footprint for Supermarkets by 175 tonnes and are working with customers to deliver a further 1.5m tonnes reduction in CO2 per year. Very importantly, we have shown that big environmental benefits can be achieved with lower packaging costs.'

Quote from Martin Leeming…Trak-Rap

The main benefits to Trak-Rap

- Demonstrates that TrakRap Stretch film can lead to a 70% reduction in weight terms as well as reducing energy used during processing compared to conventional shrink film.

<table>
<thead>
<tr>
<th>Manufacturing Stage</th>
<th>Process</th>
<th>Conventional Wrap Packaging</th>
<th>Shrink</th>
<th>TrakRap Film Packaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packaging Manufacturer</td>
<td>24.7</td>
<td>10.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit Inbound</td>
<td>1.66</td>
<td>0.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filler</td>
<td>11.3</td>
<td>0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit Outbound</td>
<td>0.1</td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disposal</td>
<td>15.6</td>
<td>4.89</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total GHG</strong></td>
<td><strong>53</strong></td>
<td><strong>16.18</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All Values in KG/Co2 per 1,000 packs Data: CCaLC Carbon Footprinting Tool

- Showing that huge environmental benefits can be achieved at lower costs. Trak-Rap has been able to align with the objectives of the Courtauld 2 industry agreement and verify the carbon savings to supermarkets using valid data from CCaLC and Lancaster University studies under the North West Eco Innovation Programme.
- Referral of potential clients from Supermarkets as Trak-Rap have been able to demonstrate the carbon savings using valid data from CCaLC and Lancaster University studies under the North West Eco Innovation Programme.
- Confidence to put Environmental benefits at the top of the agenda alongside cost, providing competitive advantage over companies in the same field due to proven environmental and economic benefits of their product
- Simplifying a potentially complex area so ensuring Stakeholder buy-in and customer approval through proven environmental benefits
- Clear, simple, presentation through “Carbon Footprint Inventory”
- Validation of claims for supply chain
- Ability to meet corporate clients Corporate Responsibility needs.
CHAPAL case by CETIM

**SME Identification**

**Presentation of Chapal**
Chapal is a company located in Loire (France), which provides different kind of manufacturing services (e.g. cutting, punching, bending, welding). It mainly produces mechanical products according to the specifications of customers, generally based in France. It is composed of 10 employees.

In a changing world, the manager of the company has decided to change the position of his company on the market. Instead of manufacturing products on demand, the company has initiated a global approach of design of new products to fulfill the market needs, integrating especially safety and environmental matters.

**Presentation of BatichapSekurit® product**

**Functions:**
The product has 2 main functions:
- Formwork to make concrete slabs (house and building construction)
- Temporary protective railing to prevent worker from falling.

**Components composing the product:**
- 1 shoe
- 1 key
- 1 pull
- 1 post.

The product is used for the construction of a building when a concrete slab has to be made. Lining boards are nailed on the shoes in order to obtain a formwork in which the concrete will be poured.

In addition, the use of posts fixed on the shoes with wooden plinths and protection net ensures the safety of workers.

The product is reusable except for the pull which stays in the concrete.
Methodology

The company asked Cetim to accompany it to have a multi-criteria approach to reduce the environmental impact of the products, but also to meet other requirements (safety, technical).

At the beginning, an environmental profile of the product was defined to know the environmental impacts of the product through its whole lifecycle (raw materials, manufacturing, use of the product, recyclability, hazardous substances, transport and packaging).

The approach showed that the main environmental impacts concern the following lifecycle steps:
- "Use of the product" (U)
- "Raw Materials" (RM): product of mainly metallic components
- "Recyclability" (R)
- Manufacturing (M)
- and to a lesser extent, "Packaging operations" (P) and of "Transport" (T).
At this phase, the company was able to define its priorities of progress, taking also into account technical and strategic aspects (market needs, image that the company wants to show to their customers etc.).

Amongst these possibilities to improve the product, CHAPAL has chosen the following design guidelines:

- reduction of use of material
- reduction of emissions of hazardous emissions during manufacturing
- improvement of the capability to recycle
- work with local suppliers

Monitoring indicators of performance on each design guideline were defined to be able to measure gains in relation with technical solutions imagined by the design office.

At the end of the design process, the ecodesigned product was improved as shown below:

<table>
<thead>
<tr>
<th>Environmental aspects:</th>
<th>M / P Raw materials</th>
<th>U Use phase</th>
<th>F Manufacturing</th>
<th>FV-R End of life</th>
<th>T Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improvements</td>
<td>Reduction of material use -9.5%</td>
<td>Reduction of material use 30.45%</td>
<td>No hazardous substances</td>
<td>Recycling facilitated by the fact that no painting was applied on the product</td>
<td>Reduction of CO2 emissions: -9.5%</td>
</tr>
</tbody>
</table>

Main benefits for the SME

The company was able to promote its products to its customers on a environmental point of view, without impacting other important criteria (cost, technical performance).
ANNEX 3: On-line survey

Production Chains Study

This survey is part of a study being conducted for Defra to determine the potential for increasing the competitiveness of UK SME manufacturers through resource efficiency improvements, in comparison with other EU member states.

By completing the survey, your feedback will directly assist Defra to quantify the resource and cost saving opportunities that may exist and understand the barriers faced by industry in realising these benefits.

Please complete this survey to help inform future decisions on policy and business support measures. The survey should take no more than 15 minutes to complete. All responses are gathered anonymously and cannot be attributed to a particular business.

You will be asked to provide basic information on your company and details of the relevant production feedstocks associated with the manufacturing activity.

The same four questions are asked for each feedstock: total quantity and cost per annum, the potential saving possible and the investment necessary to realise the saving.

Thank you for your interest and involvement.

Continue »

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*Required

**Company Data**
This section helps us understand the size and nature of your business, so that the information you provide can be correctly assigned and combined into an accurate overall picture.

**What is your primary area of manufacturing activity?**
If you operate across several areas choose the one that is most relevant to the material flows you are describing in this survey.

- Food and beverage

**Are your answers going to be based on the whole company’s operations or for a particular product line?**
Subsequent questions will cover, relevant staff levels and turnover, production inputs (materials and energy); potential savings and likely investment need to achieve these.

- Whole company
- Single product

**What is the annual turnover associated with the activity you have just specified?**

- £0 to £49K

**How many employees are dedicated to this activity?**
Answer on the basis of the number of annual full-time equivalents assigned (2 people @ half-time = 1 FTE)

- 0 - 4

**Where are you based?**
Select in which part of the UK your business, or the manufacturing operation for the particular product line, is located

- England
- Northern Ireland
- Scotland
- Wales

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Production Inputs
In the main part of the survey we are interested in your answers to the same four questions about a range of commonly used process feedstocks / inputs:
- how much do you currently use;
- how much does this cost you;
- how much of this consumption might be a realistic savings opportunity if you could improve process efficiency;
- and lastly, what would it take for you to achieve that opportunity.

We are specifically interested in six key material types plus energy and water, but we also provide space for you to let us know about other inputs which are important to you.

If one or more categories are not relevant to you just leave those sections uncompleted. If an input is relevant to you please try to provide BOTH tonnage and cost estimates.

You can navigate back and forth through the various inputs by returning to next page and selecting the appropriate option from the choices presented. Prior to final submission you can return to a page you have previously completed if you need to change your answers.

Please enter TOTAL annual amounts purchased and TOTAL annual purchase costs (i.e. not costs per unit).
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"Required"

**Production Inputs**

What would you like to do next? *
Add or amend data on...
- Steel
- Aluminium
- Plastics
- Chemicals
- Textiles
- Paper
- Another significant input in your process
- Energy
- Water
- SUBMIT finalized data

[Button] «Back  Continue »
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Steel

How much STEEL do you purchase annually?
Please answer in WHOLE TONNES. Do not use multiplying suffixes (K, M, etc.)

How much does this STEEL cost?
Please answer in WHOLE THOUSANDS OF POUNDS. Do not use multiplying suffixes (K, M, etc.) or a Pound symbol.

How much STEEL do you think you could save annually through resource efficiency?
Please answer in WHOLE TONNES. Do not use multiplying suffixes (K, M, etc.)

What investment would be needed to achieve this potential saving in STEEL?
As well as financial investment we are interested in the potential usefulness of other factors like investment of time, focus, changes to rules, etc.

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Aluminium

How much ALUMINIUM do you purchase annually?
Please answer in WHOLE TONNES. Do not use multiplying suffixes (K, M, etc.)

How much does this ALUMINIUM cost?
Please answer in WHOLE THOUSANDS OF POUNDS. Do not use multiplying suffixes (K, M, etc.) or a Pound symbol.

How much ALUMINIUM do you think you could save annually through resource efficiency?
Please answer in WHOLE TONNES. Do not use multiplying suffixes (K, M, etc.)

What investment would be needed to achieve this potential saving in ALUMINIUM?
As well as financial investment we are interested in the potential usefulness of other factors like investment of time, focus, changes to rules, etc.
Production Chains Study

Other Material Inputs

Do you have any other major material inputs not covered by our survey?
Please describe them here

How much of these do you use annually?
Please answer in WHOLE TONNES FOR ALL REMAINING MATERIALS COMBINED. Do not use other multiplying suffixes (K, M, etc.)

How much does it cost you?
Please answer in WHOLE THOUSANDS OF POUNDS. Do not use multiplying suffixes (K, M, etc.) or a Pound symbol.

How much could you save annually through resource efficiency?
Please answer in WHOLE TONNES. Do not use multiplying suffixes (K, M, etc.)

What investment would be needed to achieve this potential saving in YOUR CHOSEN INPUT?
As well as financial investment we are interested in the potential usefulness of other factors like investment of time, focus, changes to rules, etc.

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Energy

How much ENERGY do you use annually?
Please answer in WHOLE kWhr. Do not use other multiplying suffixes (K, M, etc.)

How much does ENERGY cost you?
Please answer in WHOLE THOUSANDS OF POUNDS. Do not use multiplying suffixes (K, M, etc.) or a Pound symbol.

How much ENERGY could you save annually?
Please answer in WHOLE kWhr. Do not use other multiplying suffixes (K, M, etc.)

What investment would be needed to achieve this potential saving in ENERGY?
As well as financial investment we are interested in the potential usefulness of other factors like investment of time, focus, changes to rules, etc.
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Water

How much WATER do you use annually?
Please answer in WHOLE CUBIC METRES (thousands of litres). Do not use other multiplying suffixes (K, M, etc.).

How much does WATER cost you?
Please answer in WHOLE THOUSANDS OF POUNDS. Do not use multiplying suffixes (K, M, etc.) or a Pound symbol.

How much WATER could you save annually?
Please answer in WHOLE CUBIC METRES (thousands of litres). Do not use other multiplying suffixes (K, M, etc.)

What investment would be needed to achieve this potential saving in WATER?
As well as financial investment we are interested in the potential usefulness of other factors like investment of time, focus, changes to rules, etc.

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SUBMIT finalized data

Once you click ‘Submit’ below, your data will be finally submitted to the survey and you will no longer be able to make any changes. If you need to make any further changes use the ‘Back’ button to return to the ‘Inputs’ page.

Thank you for completing our survey. After you have finished here, by selecting the ‘Benchmark Report’ link in the original invitation to participate email you will see how you compare with other respondents.

For more information on the commercial benefits of resource efficiency, and some of the business support and software tools that are available, copy the links below into your web browser:

www.wrap.org.uk/brehub
www.ecommanufacturing.eu
www.techinnovation.com/environmental-leadership

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