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PROJECT FINAL REPORT

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4.1 Final publishable summary report

Executive summary

The BoostEff project has been focused on the development of new manufacturing concepts for the paper and fibreboard industries. The targeted products play a role in everyday life for people in Europe. One of the main things that these products have in common is that they consume considerable amounts of energy and other natural resources.

In the traditional manufacturing concepts for these products a continuous stream of wood-fibres are processed into planar structures (paper or construction board), where the final material consists of a mix of the constituents of the raw material. The wood-fibre raw material is in itself a heterogeneous mix of different components and with a wide distribution in size, e.g. fibres of varying length, width and flexibility. All these components have different specific impact on product properties such as strengths and surface smoothness.

The project goal has been to develop future manufacturing concepts where the final product has a tailor-made layered structure: fibres and other materials are placed at the optimum position with respect to the required product functionality. This enables manufacturing of products that have similar or better properties compared to conventional products, while at the same time reducing the need for wood-fibre raw material and energy. Indeed if you reduce the use of raw material for a given product energy can be saved in the entire production process.

The developed future manufacturing concepts have been based on a set of available technologies. These concepts were demonstrated to have clear impacts on the targets, which were:

- Energy efficiency increase > 20%;
- Reduction of emissions of CO_2 and other Green House Gases (GHG) > 20%;
- Raw material savings > 20%;
- Operating cost reduction > 10% or productivity increase > 10%.

The results clearly show that the future manufacturing concepts have a huge potential in improving energy and raw material demand, environmental footprint as well as competiveness. Furthermore, the developed concepts show short payback time for the investments needed in order to implement these industrially.

The chosen future manufacturing concepts have had the sole purpose of meeting the targets of the BoostEff project. However, the suggested concepts offer a high degree of flexibility when it comes to what type of products could be obtained and how to make the best benefit of these. Thus it is possible to apply the concepts towards other targets such as e.g. product quality or other product ranges. In addition, since each of these concepts is based on a product specific set of technologies other combinations of these technologies have been identified within the project that can be applied to other products within the industry.

A wide application of the developed concepts and technologies would play an important part in securing the competitiveness of the paper and fibreboard industry in Europe.

Project context and objectives

The vision of BoostEff was to develop new innovative manufacturing concepts for wood-fibre based products giving a significant reduction in environmental footprint. The targeted products were paper and construction board, products that play a role in everyday life for people in Europe. One of the main things that these products have in common is that they consume considerable amounts of energy and other natural resources.

Concept

In the traditional manufacturing concepts for these products a continuous stream of wood-fibres are processed into planar structures (paper or construction board), where the final material consists of a mix of the constituents of the raw material. The wood-fibre raw material is in itself a heterogeneous mix of different components and with a wide distribution in size, e.g. fibres of varying length, width and flexibility. All these components have different specific impact on product properties such as strengths and surface smoothness.

The project goal has been to develop new manufacturing concepts where the final product has a tailor-made layered structure: fibres and other materials are placed at the optimum position with respect to the required product functionality, see Figure 1. This enables manufacturing of products that have similar or better properties compared to conventional products, while at the same time reducing the need for wood-fibre raw material and energy. Indeed if you reduce the use of raw material for a given product energy can be saved in the entire production process.

The generic process concepts that have been targeted permit advanced fibre selection from the raw material stream, modification of fibre properties followed by the production of layered tailor-made material structures. By combining these concepts new product grades can be manufactured replacing current grades.

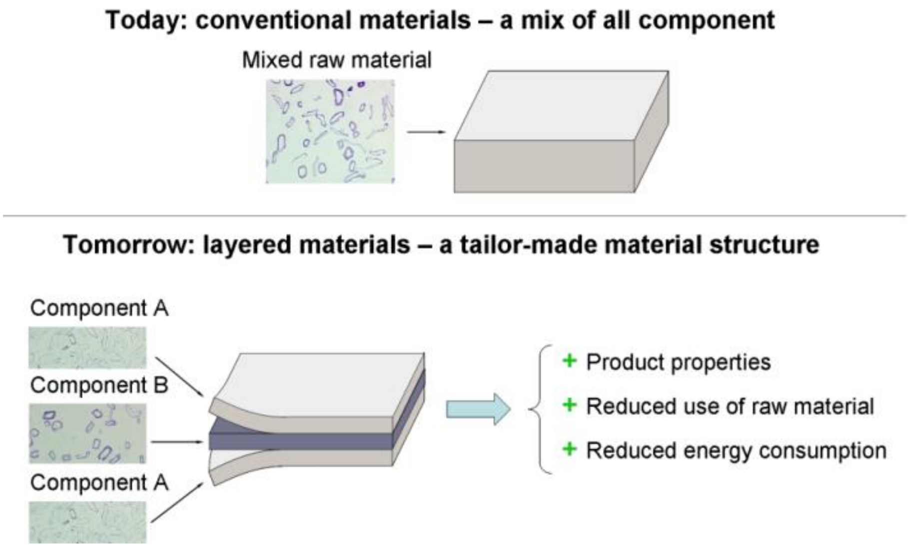


Figure 1. Tailor-made products.

Objective

The objective of the project was to demonstrate significant reductions in energy and raw material demand in pilot- and mill-scale. In order to achieve this, the project was based on the focused development of three demonstrator platforms. At the end of the project, these platforms describe future manufacturing processes for the selected products describing the whole production chain as well as the environmental and economic impact. These concepts are referred to as *Future Manufacturing Concepts* and the intent with these was to enforce a strong industrial focus.

In order to clearly demonstrate the impact and industrial applicability the developed future manufacturing concept are based on existing production units of the industrial partners and deal with the production of three commodities in European society:

- *Uncoated magazine paper, specifically supercalendered (SC) paper*
- *Coated magazine paper, specifically light-weight coated (LWC) paper*
- *Construction products, specifically Medium density fibreboard (MDF) and hardboard*

The individual goal for each future manufacturing concept was to demonstrate that it is possible to reduce the environmental footprint and increase the competitiveness by achieving at least three of the following criteria:

- Energy efficiency increase > 20%;
- Reduction of emissions of CO_2 and other Green House Gases (GHG) > 20%;
- Raw material savings > 20%;
- Operating cost reduction > 10% or productivity increase > 10%.

The development and demonstration of these concepts was performed in unique pilot facilities as well as at the specific production units. Thus the technological performance has been demonstrated in an industrially relevant scale, which will allow quantitative evaluation of the impact on product properties. This will also facilitate impact evaluation as well as industry and consumer acceptance. Based on these results the overall effects and the impact on the call targets as well as on competitiveness can be demonstrated.

It is anticipated that the three future manufacturing concepts will be industrially implemented and that they will serve as foundation for a future widespread implementation, within the targeted industrial sectors. Therefore a considerable effort has been made to develop modelling tools for future prediction of impacts for other production units and products within the industrial sectors.

Furthermore, the development of these future manufacturing concepts has included dedicated work on preparing the data necessary to proceed with investment projects at the targeted production units at the end of the project. This includes, apart from the impact on reductions in production costs, the specification of costs related to the necessary investments needed for implementing the new processes. The goal is that these results will be applicable not only for the three production units chosen but also as a basis for decisions on investments in other production units within the two industrial sectors, represented in BoostEff.

Advances beyond the state of the art

The targeted products, paper and construction board, are commodities in general use and their production is based on processing a continuous stream of wood-fibres into planar structures. The common denominator for these is that the raw material is handled as a single stream during all stages of the manufacturing process. However, the composition of the raw material is heterogeneous with fibres and particles of varying morphological features such as length and flexibility. This means that the micro structure and the resulting mechanical properties of the products are given by the mix of the constituents of the raw material.

In order to bring the production processes clearly beyond state-of-the-art the project has implemented the following process concepts in pilot-scale and mill-scale demonstration:

- *Optimised layered sheet structures through stratified forming:* the possibility to create layered products has the potential to improve quality and to reduce costs for raw material, energy and investments. The layering technique also has the ability to dose chemical additives locally in the headbox thereby improving product properties.
- *Advanced fibre fractionation:* new tools can select fibres based on their morphology and their potential impact on the properties of the final product. The different fractions can undergo *selective modifications,* depending on their nature and on their functionality in the final product.

Within the fibre board area the project has implemented the ideas these regarding layering, fractionation and selective modification taken from the papermaking area. This has meant that the starting point was different from that of the papermaking tracks and that the suggested technologies are less mature. Hence more focus has been put on initial developments and industrially relevant demonstration of potentials. This has been very successful and the project clearly demonstrates that ideas can be abridged from one sector into another.

These process concepts that have been implemented into the manufacturing processes are all based on recent technological developments, which mean that these techniques independently represent possibilities beyond state-of-the-art. The future manufacturing concepts that have been developed in the project, which are based on an optimum fit between the identified technical solutions, move the whole manufacturing processes well beyond state-of-the-art.

By performing these activities BoostEff has also advanced the current know-how on fractionation with screens and hydrocyclones, which is based mainly on laboratory results and limited pilot-scale trials, to full-scale industrial processes. These results will, by themselves, allow significant steps beyond state-of-the-art when implemented in industrial production units.

Project structure

BoostEff has been a three year project organized as ten work packages. The outline of the project can be found in Figure 2. Within the project two work packages, WP1 and WP2, were devoted to co-ordination and dissemination/exploitation respectively. The first half of the project was mainly performing research and technical development activities focused on identified new technologies. The second half of the project was focused on demonstration of the developed concepts in pilot-scale and mill-scale.

WP3 was the starting point where the effect of available and future technologies as well as new ideas was estimated. It also provided an analysis of the present state-of-the-art. Significant work was made to develop models for predicting the impact on product properties and process efficiency. This was of vital importance for the work performed in WP4 – 10 as well as for implementation of the future manufacturing concept for other production units and other products in the future.

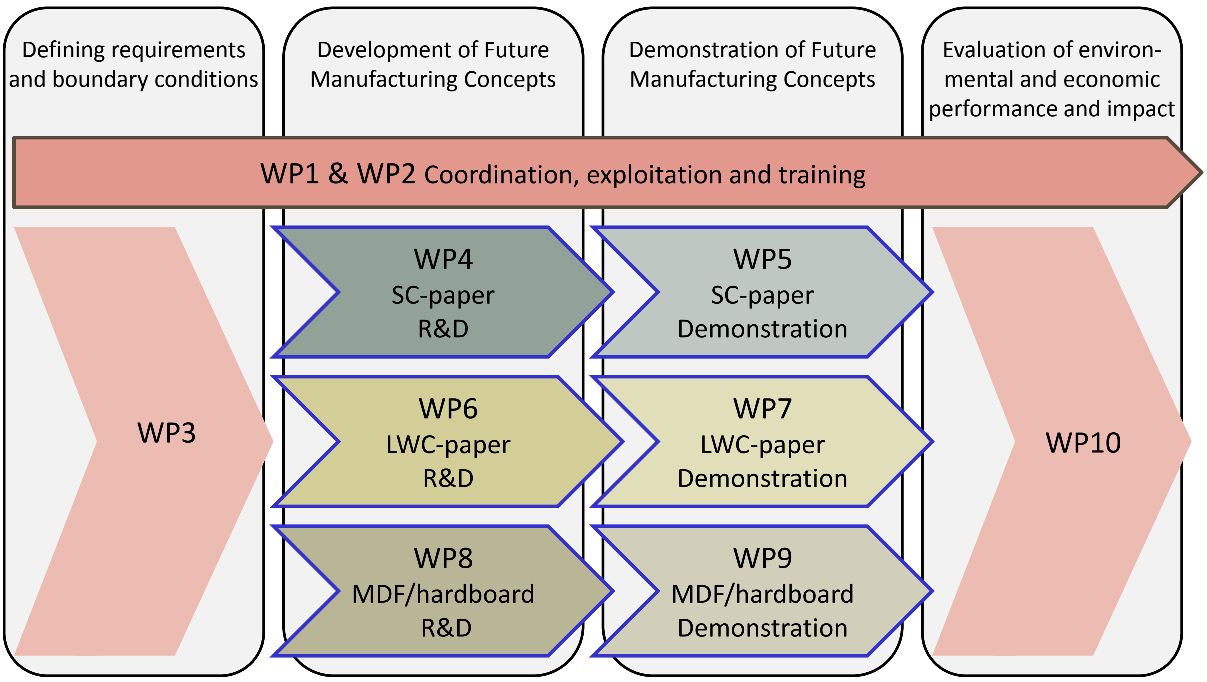


Figure 2. Overview of the work packages in the BoostEff project.

Within the project the three future manufacturing concepts was developed within two work packages each. The first of these two work packages aimed at research and technical development work focused on these concepts and the second was focused on demonstration. Thus the six work packages (two per future manufacturing concept formed the core of the project. Industrial partners were actively participating in leading the work in these work packages, which ensured a strong focus on innovation and industrial relevance.

- WP4 and WP5 was devoted to the development of the future manufacturing concept for SC-paper
- WP6 and WP7 was devoted to the development of the future manufacturing concept for LWC-paper
- WP8 and WP9 was devoted to the development of the future manufacturing concept for MDF and hardboard

WP10 was an integration work package where the environmental and economic/market impact was evaluated. This work was performed iteratively in the project in cooperation with the other work packages. During the first half of the project this WP developed the methodology and defined the state-of-the-art.

The project goal was to implement new technologies. Therefore it was envisaged that new industrial partners would be needed. After identification of suitable partners three new industrial companies entered the project about one year after start-up.

Science and technology results

The Future Manufacturing Concept for SC-paper

Objective

The overall objective of the work performed towards manufacturing of uncoated magazine paper or SC-paper was to demonstrate significant reductions in energy and raw material demand in pilot-scale and mill-scale for the production of SC-paper. The target machine for this development was the production unit at Stora Ensos Kvarnsveden mill in Sweden.

In order to achieve this, research and development on a set of identified technologies was performed, which together formed the future manufacturing concept for SC-paper. A demonstrator platform was developed for the concept and the effect of the future manufacturing concept was demonstrated with respect to energy and fibre input but also the possibility to compete with higher-quality paper grades.

Scientific and technical results

The following technical solutions were chosen to be included in the future manufacturing concept for SC-paper:

- A stock preparation process based on fractionation to treat the worst fraction separately
- Switching from a single layer paper sheet to a stratified sheet using fibre and filler layering as well as layering of chemical additives
- Strength additives for increased sheet strength

Regarding a new pulping process a set of process solutions was identified and evaluated. This included benchmarking of the properties of fibre properties on several positions at the Stora Enso mill in Kvarnsveden. Based on these results possible combinations of technologies were identified. After initial screening if these combinations pilot-scale trials were performed in order to identify the best ways to fractionate the stone ground-wood mechanical pulp (SGW-pulp) and how to perform post-treatment of the obtained fractions. Apart from evaluating the impact on fibre properties a significant amount of work was also performed based on laboratory stratified sheets using the obtained fractions. In parallel the possibility to stratify the ingoing components in the SC-paper, e.g. mechanical pulp, chemical pulp and fillers. It was shown that significant effects can be obtained with the obtained fraction but that the sensitivity of layering the ingoing raw material components was stronger. The primary impact of fractionation was related to energy savings. Based on these result a new pulping process was proposed where the whole production is processed through a fractionation stage where the worst fraction is separated and refined separately. The proposed solution demonstrated a significant impact on the energy demand of the pulping process, see Table 1.

It was assessed that this process solution will have significant impact on energy demand with maintained product properties. The solution could not be demonstrated as a complete process. However, the proposed future manufacturing pulping process is built-up of two steps where the first step is similar to today's process and the second step is based on fractionation of the whole pulp combined with LC-refining of the worst fibre fraction. Therefore the first step was demonstrated in mill-scale and the second step did not need demonstration since the concept is commercially available and a well-known technology. However, in order to estimate the impact for this step, data regarding the effect of fractionation for the specific pulp is needed, which was available from the earlier results obtained.

System	Tensile index in	Total specific	Energy consumption

	final pulp	energy kWh/t	compared to existing system
Existing	**50**	**2022**	
FMC with increased quality	**53**	**1842**	**-9 %**
FMC at equal quality	**50**	**1745**	**-14 %**

Table 1. Demonstrated effect of the proposed future manufacturing concept (FMC) for the SGW-pulp production.

Regarding the sheet forming process significant efforts were made to identify and evaluate sheet stratification concepts. These consisted of a wide variety of sheet structure where fibre type and/or fillers were added to different layers including the use of the added possibilities given by the Aq-vane concept, see Figure 3.

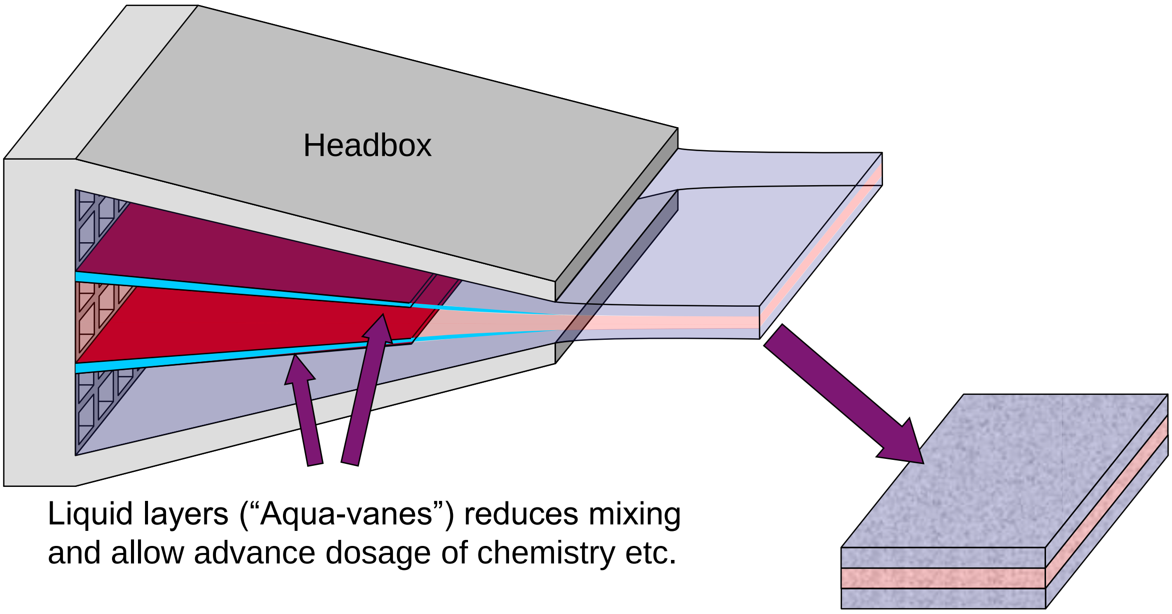


Figure 3. The Aq-vane concept, which is one of the starting points of the technology. Conventional separation vanes/separating elements that have been tested for sheet stratification are flexible but solid structures. This leads to large scale mixing at the end of the vanes and thus mixing of the fibre layers. The detrimental effect of the wake can however be reduced by adding a third stream of liquid, i.e. the Aq-vane(s). Small scale mixing between the liquid layer and the pulp flows will still occur, but the large scale mixing between the two pulp layers is significantly reduced.

Furthermore, the implementation of the Aq-vane technology itself was pursued in the project, with significant efforts on the development of a design that is industrially viable. The result can be seen in Figure 4, where a series of images showing the industrially viable headbox that was developed within the project. This headbox incorporates the Aq-vane technology and can here be seen mounted in the pilot paper machine at Innventia. Demonstration of the functionality of the developed headbox and that it can produce good layered structures was performed in pilot-scale.

Regarding the effect of sheet layering significant development was performed in pilot-scale where the impact of the structure of the produced sheets was evaluated. As a result of these trials a final concept for the future SC-paper was devised. This concept was demonstrated in pilot-scale using extensive trials where care was taken in order to accurately evaluate the effect of the concept.

During the demonstration trials each chosen operating point is characterised by a set of specific forming condition such as machine speed, filler content and level of dosage of chemical additives. Order to build confidence a jet-wire speed difference curve was performed for each of these operating points.

Figure 4. The stratified headbox developed by Andritz, mounted in the FEX pilot paper machine (left, top and bottom). To the right (top) a three layered jet can be seen entering into the paper gap former. Finally at the inspection window mounted in the contraction of the headbox nozzle shows a clearly three-layered structure during the layering demonstration trials.

The jet-wire speed difference means that the jet speed coming out of the headbox is deviating from the speed of the wire (forming fabric) where the web is built up. By performing this curve for each operating point the validity of the data can be ensured. Generally all properties of the sheet are sensitive to this parameter which means that in practice only the minimum point should be considered for comparison with other results. The sheets manufactured with the new concept were than compared to reference sheets made with standard technology. Furthermore, the effect of calendering and print was demonstrated in pilot-scale on the sheets produced.

The produced paper samples, i.e. the future manufacturing concept as well as the reference, were compared to the existing product and met all requirements regarding optical properties and print quality. Regarding the impact on runnability in the paper machine and printing press the results obtained in the demonstrations can be seen in Figure 5. In the graph the fracture toughness for the reference is shown together with fracture toughness of sheets produced using the Aq-vane technology. The latter contains two variants, with high and low shear in the approach flow (shear=turbulence). Fracture toughness is the strength measurement that has the best correlation with runnability and in the graph three levels of filler content is plotted. As can be seen the jet-wire variation gives changes in fracture toughness for each set. The minimum point is marked with grey and used as basis for regression lines. From these it is clear that the Aq-vane gives the same fracture toughness index at 45% filler content as the reference at 35% filler content. Thus the product can be manufactured using more filler using the Aq-vane technique.

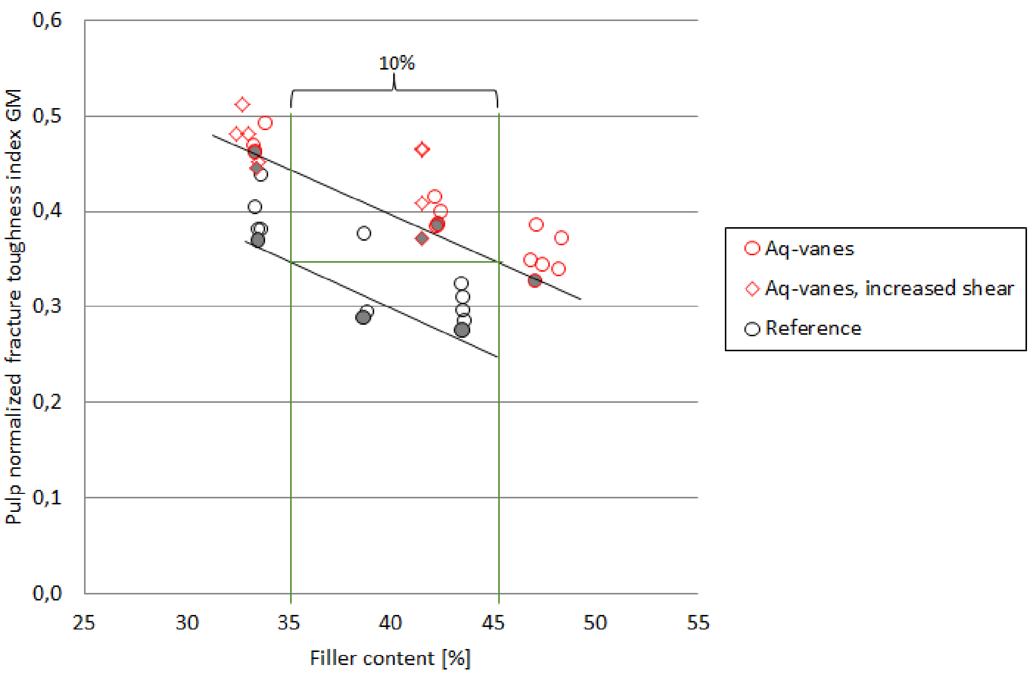


Figure 5. Demonstrated strength of the paper indicated through the use of the fracture toughness value, which gives the relation to runnability in the paper machine and printing press. Produced Pulp normalized means that the variation of pulp properties has been compensated for. The minimum point in the jet-wire speed difference curves have been market with grey. By plotting the regression of the minimum jet-wire speed difference curves it is possible to the potential for replacing fibre raw material with fillers.

Finally the use advanced chemical additives was evaluated. Research and development work was initially performed in laboratory scale focused on (*i*) developing concepts for general strength enhancement and (*ii*) developing a dedicated system for the use together with the Aq-vane technology and the additional possibilities this gives. The results were promising, clearly indicating the potential for strength enhancement. Therefore, as a part of the demonstration activities in pilot-scale, a specific trial was performed where the impact was. The result can be found in Figure 6. In the figure the reference can be seen as well as the effect of strength additives. Apart from these results it was demonstrated that the SC-paper produced with the future manufacturing concept had a very positive response to calendering, giving a clear improvement in strength.

Given the demonstrated results in pilot-scale as well as in mill-scale the following effects of the future manufacturing concept were shown:

- If we the Aq-vane technology is used as defined in the future manufacturing concept we can replace 10% of the paper basis weight (dry content) with fillers.
- The strength additive gives that we can replace 6% of the paper basis weight (dry content) with fillers.
- Finally, the effect of calendering gives the possibility to reduce the filler content with 4% of the paper basis weight (dry content) with fillers.

When these effects are combined and utilised to 2/3 of their demonstrated potential this gives a decrease in total decrease basis weight with 3% and increase in filler content with 11%.

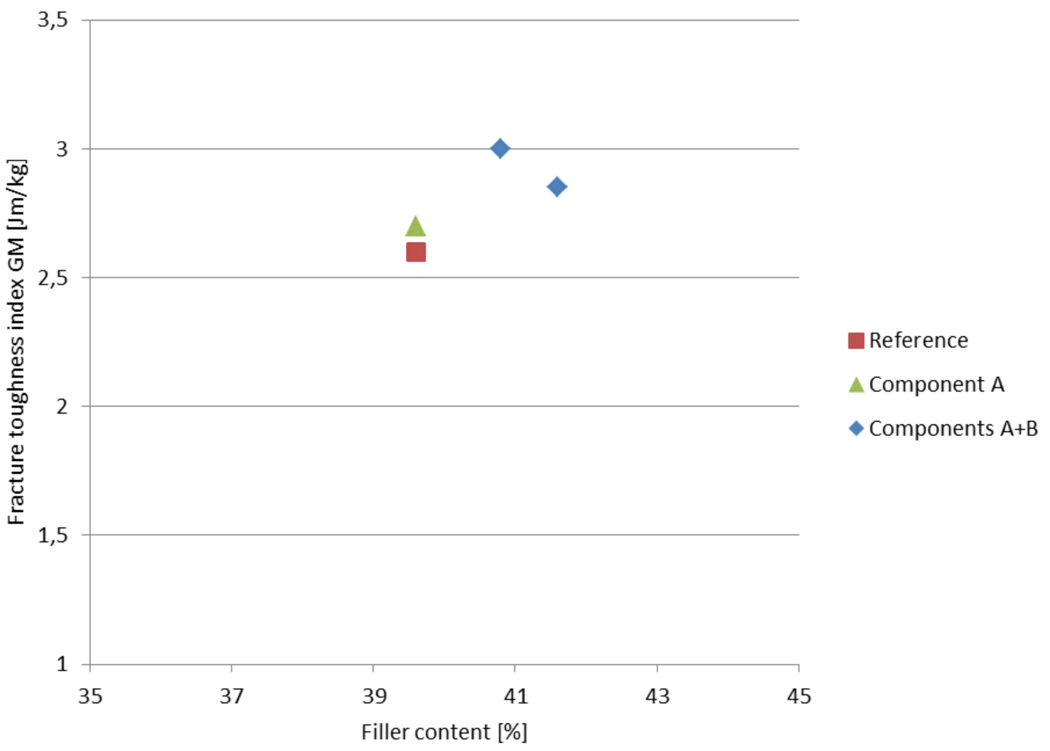


Figure 6. Demonstrated strength effect of the strength additives.

The Future Manufacturing Concept for LWC-paper

Objective

The objective of the work in BoostEff towards coated magazine papers has been to define a future manufacturing concept for LWC-paper. Research and development work has been performed in order to develop and adapt the technology that has been put into this concept and the result has been demonstrated in pilot-scale.

Initially the work was focused on LWC-paper made out of recycled pulp (DIP), but due to changes at the Holmen Madrid mill the work was widened to include LWC from virgin pulp (TMP). In order to do this the mill at Stora Enso Corbehem was chosen as the target production unit. Thus new manufacturing concepts have been defined for DIP based as well as TMP based LWC-papers.

Scientific and technical results

The following technical solutions were chosen to be included in the future manufacturing concepts for LWC-TMP and LWC-DIP:

- Switching from a single layer base-paper sheet to a stratified sheet, which should allow reduction of the base paper grammage
- A stock preparation process based on fractionation to treat dedicatedly each of them at improved efficiency and reduced cost, and preparing the fractions for the stratified headbox
- Curtain coating of the stratified sheet which should allow to reduce the coating layer grammage compared to conventional blade coating

Paper stratification indeed allows masking the coarse elements of the pulp in the internal layer while improving mechanical and surface properties. This also allows reduction of the grammage of the paper thanks to an increase of its bending stiffness and bulk. Indeed, an increase of 40% of the bending stiffness will allow a grammage reduction of the base paper by 10 %. Additionally, if a smoother surface can be obtained, a lower grammage of coating layer at identical properties could be obtained.

By having a stock preparation process, see Figure 7, which can separate the different fractions for paper stratification allows (*i*) to have dedicated treatment on each of them instead of applying all treatments on the whole pulp and (*ii*) to place them a the position in the stratified sheet where it has the best impact on the product properties. This allows a more suitable treatment for each fraction giving increased pulp quality and reduced costs.

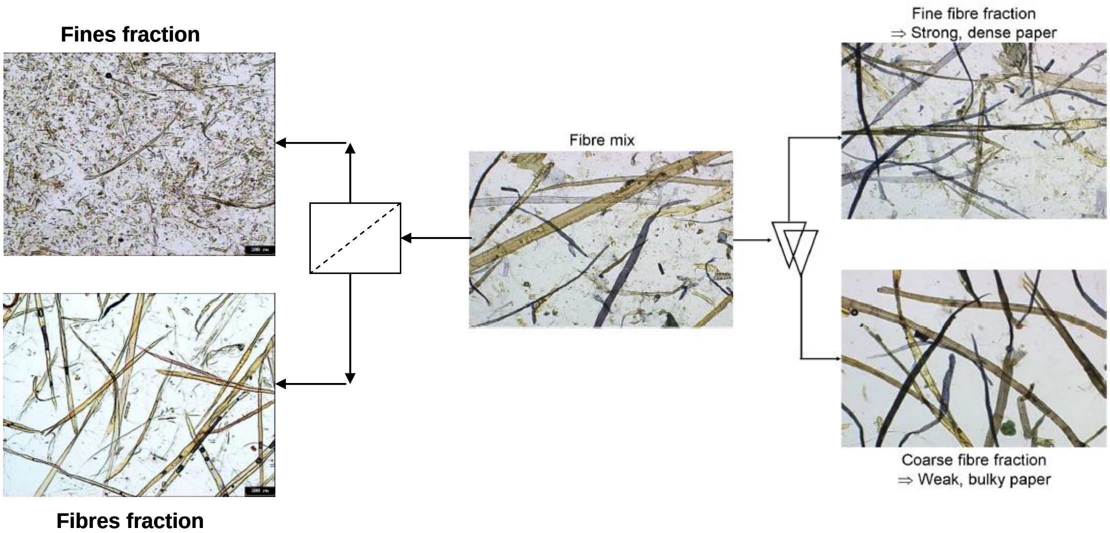


Figure 7. Future manufacturing concept for the base-paper of LWC-paper: stock preparation based on fractionation of the pulp fractions, and dedicated

treatment of each fraction.

Finally, the application of the curtain coating technology, Figure 8, which is known to give a better coverage of the paper surface, should allow reduction of the grammage of the coating layer deposited.

As part of the work performed it was demonstrated that several fractionation technologies, combined together, permits an efficient separation of various components of a pulp suspension. The combination of screen fractionation together with hydrocyclone fractionation have indeed allowed to produce two categories of fibres and two categories of fines:

- Bonding, flexible fibres (F1), more concentrated in early wood fibres
- Coarse and rigid fibres (F2), more concentrated in late wood fibres
- Coarse fines (f2), containing small rigid cellulosic fines, more lignified
- Bonding, high specific surface, cellulosic fines (f1)

When these fractionations are applied to recycled pulp, contaminants are concentrated into a specific stream, which can be treated adequately. For instance specks particles with stickies are concentrated into the F2 fractions, whereas inks are concentrated, with fillers in the fines fraction. Thanks to this fractionation technology combination, new recycled fibre process has been designed and patented. It allows to gain yield and concurrently to reduce sludge produced, to reduce energy demand and to reduce chemical dosages.

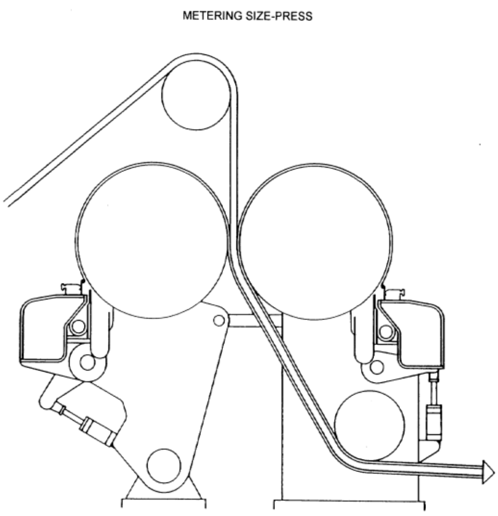


Figure 8. Conventional single-layer coating of LWC base paper (left) the future manufacturing concept of curtain coating of LWC base paper using stratified coating layers (right).

A similar solution was also applied to a mechanical pulp stock preparation process. This gives the possibilities to efficiently the large shives, which need to be treated adequately. Similarly a new TMP stock preparation process was designed and tested successfully at pilot-scale, leading, combined with adequate treatments on each flux, to 10% reduction in energy demand (3300 reduced to 2970 kWh/T).

The obtained fractions were then used in a stratified sheet structure according to their best impact on final product properties, see Figure 9. This permits the increase in several properties such as tear strength (+22 %), tensile strength (+6 %) and burst (+8%) but above all bending stiffness (+25 %) and bulk. The distinct effect of different fibre fractions can be seen in Figure 10. The F2 fraction gives a thicker or more bulky sheet whereas the F1 fraction gives a thinner and thus less bulky sheet.

These effects allow a grammage reduction at maintained strength. From laboratory experiments up to a 10% reduction in grammage was predicted since 6% were obtained (corresponding to an increase of 25 % in bending stiffness) with several identified ways for further optimisation.

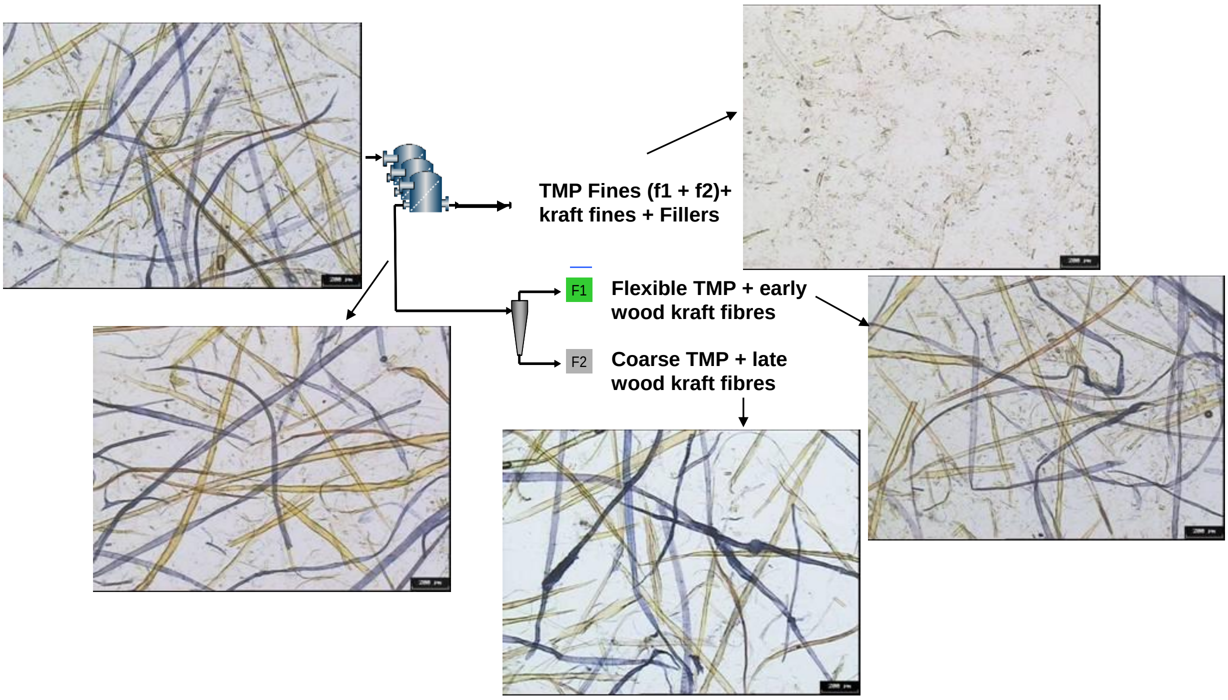


Figure 9. Simplified fractionation process to produce two categories of fibres (early (F1) and late (F2) wood fibres) and one fines fraction.

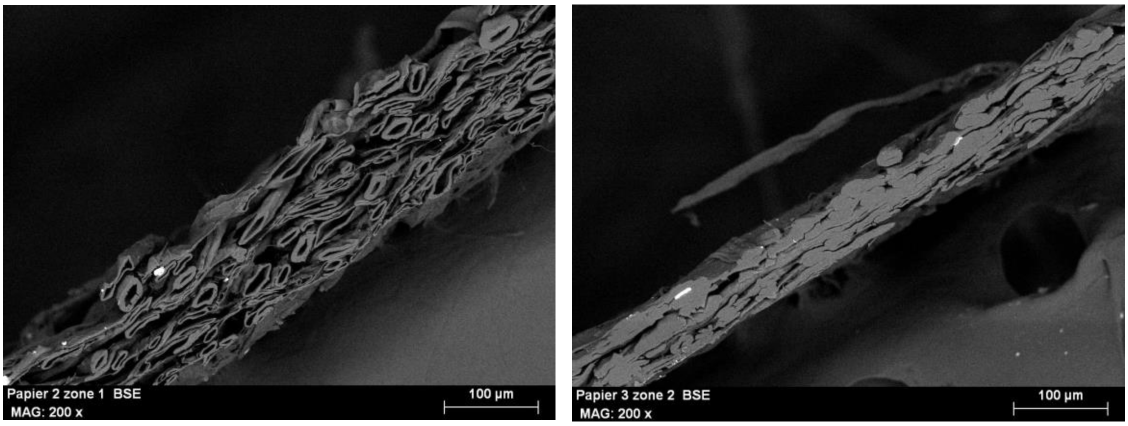
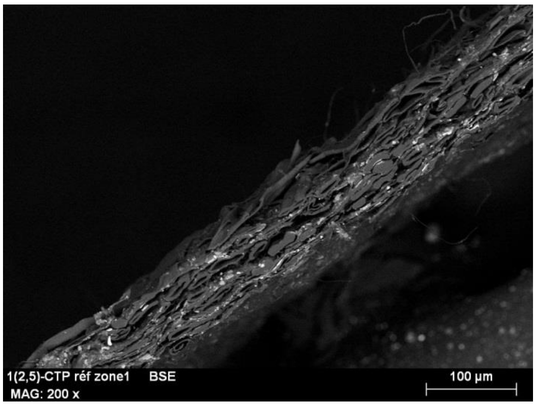


Figure 10. Images showing the thickness of sheets made of F2 fibres (left) or F1 fibres (right).

The result was a sheet that requires the adequate location of the various fractions in a 5 layer structure for optimal impact. The structure can be seen in Figure 11. One major rule of thumb is to locate the very coarse fibre fraction in the centre of the sheet, providing higher thickness and therefore increasing bending stiffness and bulk. This concept was demonstrated at pilot-scale where a stratified five layer base paper of 48 g/m² was produced. This combination of the fractionation and stratification has led to a patent application.

The last main component of the future manufacturing concept, namely curtain coating, allows a reduction in coating colour grammage at identical coverage. This possibility was demonstrated in pilot-scale. Equal optical properties was obtained with 9 g/m² coating colour using curtain coating compared to 11 g/m² for conventional blade coating, see Figure 12, as well as an equal printability. An even higher reduction was predicted for the stratified base-paper structure as a result of a smoother surface. This was shown at lab scale but the demonstrated stratified structure did not give reduce surface roughness. Thus, this further reduction (down to 7 g/m²) could not be demonstrated. However, investigations on solutions that can handle this problem have been performed.



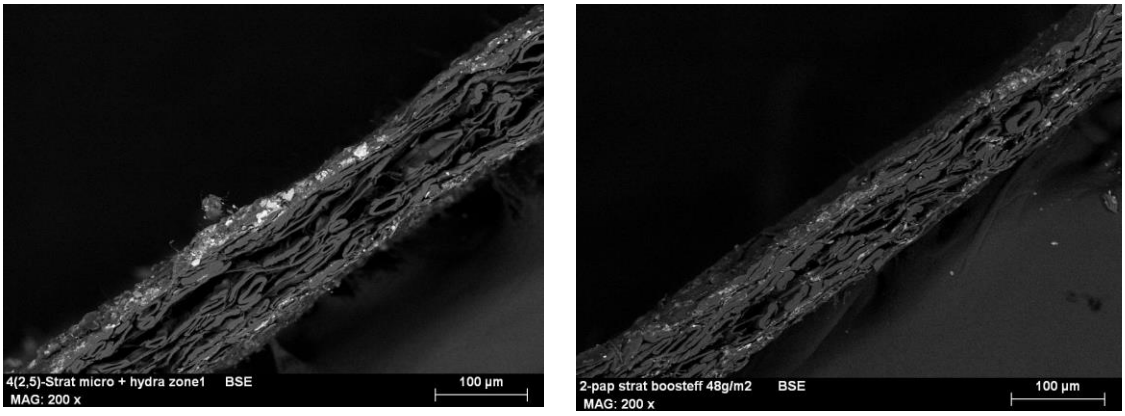


Figure 11. Conventional one layer paper (top), optimised stratified sheet obtained at lab scale (bottom), pilot demonstrated stratified 5 layers paper structure (bottom right).

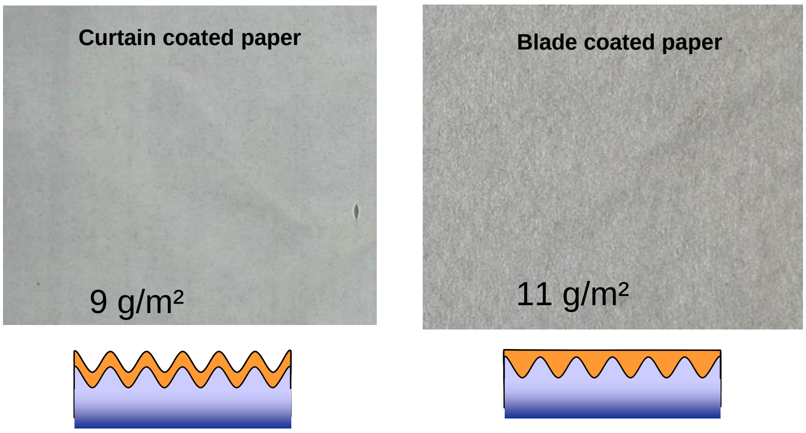


Figure 12. Curtain coated paper (9 g/m²) versus conventional blade coated paper (11 g/m²). Demonstration in pilot-scale.

The future manufacturing concept for Hardboard and MDF

Objective

The objective of the work in BoostEff towards fibreboard has been focused on MDF and hardboard. The work aimed at improving fibreboard production, considering both wet and dry processes.

It was performed in parallel towards these two products and target productions units were found at Tarnais de Panneaux for hardboard and at Unilin for MDF. Research and demonstration was performed in laboratory scale, pilot-scale as well as in mill-scale. Since future manufacturing concepts were designed suitable for each of these products they are presented for each manufacturing process separately.

MDF

MDF production is a process well optimised, with many improvements performed in the past. Work has been focused on raw material savings and improvement of final product. The following technical solutions were chosen to be included in the future manufacturing concept for MDF, see Figure 13:

- Replacing virgin fibres with selected recycled fibres
- Fibre surface modification
- Board surface roughness control

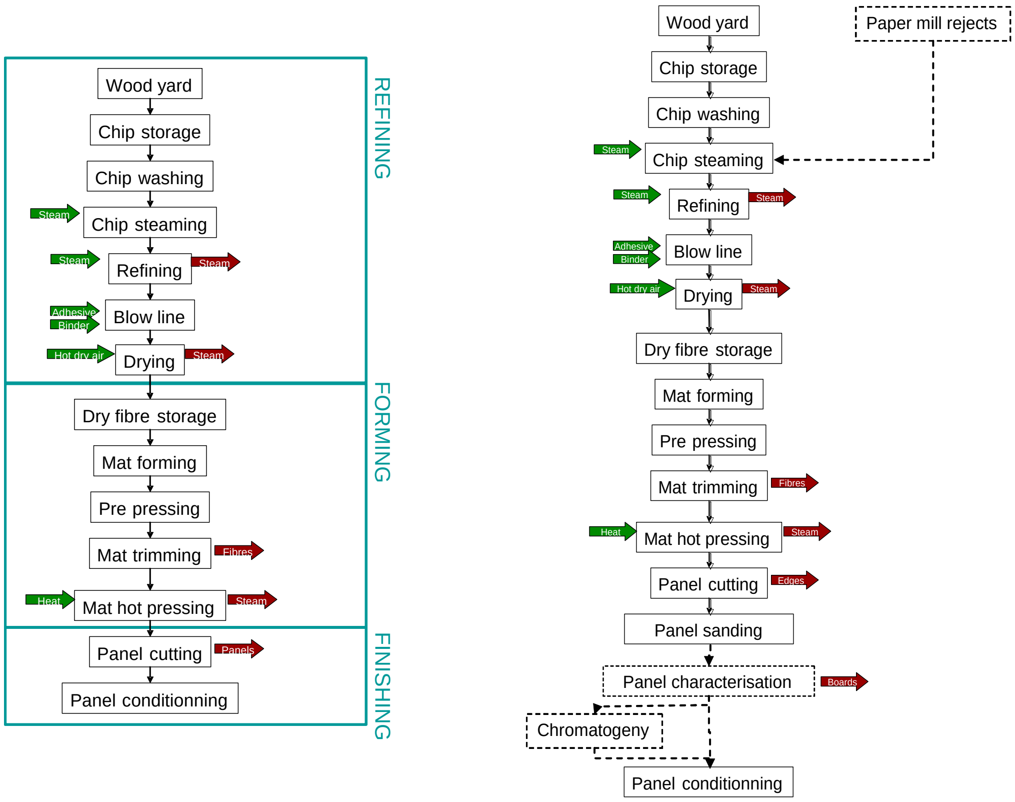


Figure 13. The traditional MDF manufacturing process (left) and the suggested future manufacturing concept for MDF (right).

Regarding the use of reject fibres research and development was performed in pilot-scale and demonstration in mill-scale. It was shown that the chemical composition of the recycled fibres was compatible with standards and that the fibre morphology, for some of the material, was very close to fibres produced in a mill. The most promising paper reject source was selected and used as a direct substitution of wood chips without any process modifications. Pilot trials showed that 20% of recycled fibres could be introduced without altering product properties.

The MDF properties were slightly lower than the reference but still above recommendations. However, some spots were observed on the surface due to the presence of non-fibrous material, such as polystyrene balls or hot melt glues collected during paper reject recovery. In order to limit the presence of such contaminants, cleaning could be necessary before paper rejects are introduced into MDF process. In order to prove this test were performed, which showed that this problem could be handled perfectly.

The concept was demonstrated in mill-scale and the boards produced showed mechanical characteristics in accordance with European standards. The paper rejects introduced requested small amount of energy compared to defibration of wood-chips as no fibre separation was needed. In addition, dry matter content of rejects obtained after pressing was similar to wood, rendering it possible to use the dryer section without any modification. The mill-scale demonstration showed that the introduction of 5% of rejects resulted in slightly reduced properties. Thus, selected paper reject can partially replace virgin fibres.

Regarding fibre surface modification, it aimed at improving water resistance of boards, which would be a way to reduce paraffin used into process or expanding the use of fibre boards in humid conditions without resin modifications. The method used was chromatogeny, which is a treatment based on long carbon chain acids that reacts covalently with carboxyls of lignocellulosic materials. The effect of chromatogeny was demonstrated on boards produced in lab-scale as well as in pilot-scale. The results showed that water resistance was improved, specifically for short term exposure. However, when applied to mill produced boards the presence of paraffin or higher resin content reduced treatment efficiency. As a consequence, if this technique was found very promising, it would require further optimisation, considering resin in the board as variable parameter.

Board surface characterisation aimed at controlling quality after sanding. This measurement would be a way for mill to better handle quality at the end of process, improving efficiency. Based on laser triangulation, this technique allowed characterising boards in the out-of-plane direction, i.e. surface roughness. Demonstrations performed in industrial conditions gave interesting and promising results, Figure 14. Indeed, the measurements provided by the sensor (roughness indexes) corresponded to expectations: 5 – 6 microns for very smooth panels, between 7 and 13 microns for "normal and acceptable" panels, and more than 15 microns for non-compliant panels. In addition, these measures were very stable, independent of the panels thicknesses tested, and well correlated with the finishing grain used on the sander. As a consequence, a roughness evaluation was possible, making it possible fast trouble shooting and on-line quality controls.

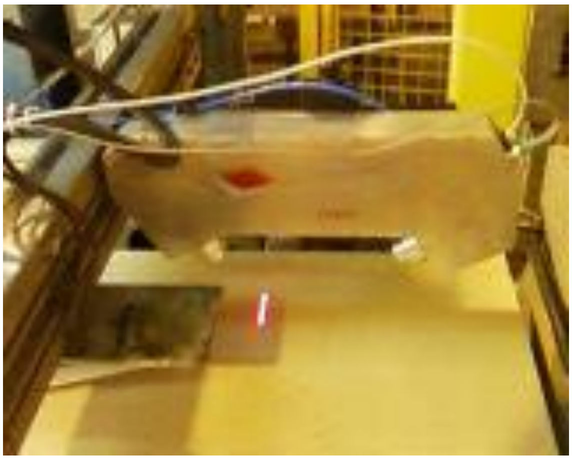


Figure 14. Sensor installed on processing line of MDF

Solutions developed and described were proven at pilot or mill scale and showed high relevance, in accordance with mill expectation. Significant energy savings can be expected by applying these, reducing carbon footprint and process efficiency. Still improvements and further optimisation need to be done. One possibly would be to introduce rejects later into process, after the refiner, to reduce material flow through the refiner and limit resin demand. This later parameter, as it represents almost half of the total carbon footprint, would be the most relevant to consider. Surface characterisation constituted a very promising solution, with a quick return on investment. Further work will continue focused improving how to use/interpret the sensor results. Finally, board surface modification needs improvement but will, in a near future, result in a breakthrough for water resistance improvements.

Hardboard

The following technical solutions were chosen to be included in the future manufacturing concept for hardboard, see Figure 15:

- Replacing virgin fibres with selected recycled fibres
- Fibre modification
- Sheet/board stratification
- Board surface roughness control

Processing of hardboard made it possible to consider various improvements at several steps of this process.

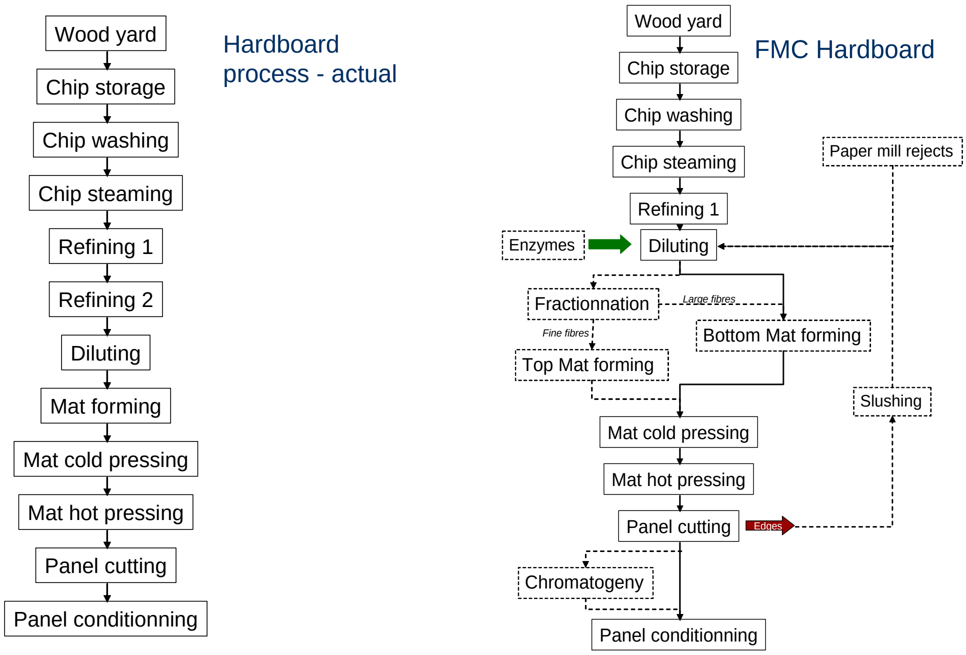


Figure 15. The traditional hardboard manufacturing process (left) and the suggested future manufacturing concept for hardboard (right).

Regarding the aim at reducing wood virgin fibre use by considering alternative sources, this solution would result in reductions in energy demand for refining and steam production and as well as a reduced carbon footprint, since the considered alternative fibre sources, i.e. recycled fibres, are used as fuel or land fill. As for the MDF application, the recycled fibres present properties compatible with is obtained with traditional hardboard processing of virgin raw material. Different paper mill rejects were considered, which had been subjected to different processing. Among them, some were found suitable for partial substitution of virgin fibres. Several proportions were tested. For several grades, it was found that up to 20% were possible as a direct substitution of virgin fibres. It was demonstrated in mill tests that this solution is viable and long-lasting.

Another source was also identified, which is available directly at the mill. The source is hardboard edges or boards not reaching product specifications. Since these are constituted of individualised fibres, these materials were identified as promising sources. Indeed, by developing and applying adapted slushing conditions, full defibration was achieved and it became possible to mix them with virgin fibres, in various amounts. The results obtained demonstrate that quantities up to 8% could be added without significant reduction of properties. In fact, characteristics were almost similar as those produced from virgin fibres.

Second part was devoted to board properties improvement. In order to stabilise and even increase board qualities, considering alternative fibre sources introduced as fibre furnish, enzymes were considered, seen as chemical modifications. These were introduced in a chest before mat formation and lasted for one hour. Temperature and pH were kept compatible with their activity. Results showed significant improvements of board strength and water resistance. Another advantage was the compatibility of this treatment with actual process, requiring limited investments as chemicals were added directly into an existing tank.

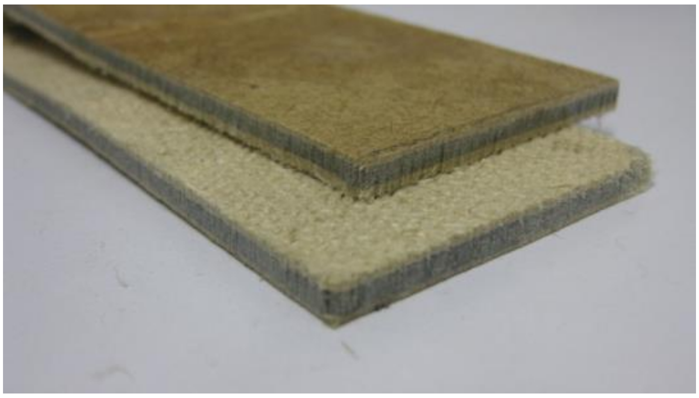


Figure 16. Picture of hardboard produced with layering and paper rejects in middle layer.

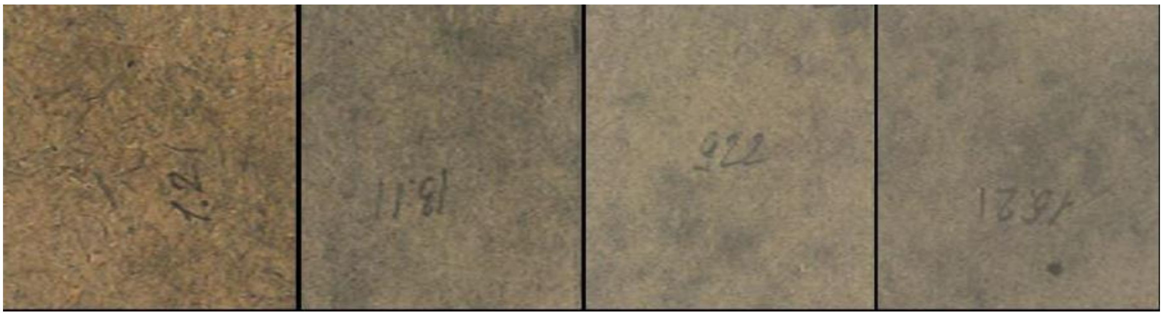


Figure 17. Example of hardboard covered with increasing proportion of fine fibres onto the surface (from left to right 0 – 10 – 20 – 40%).

Additionally to enzymes another part of the future manufacturing concept was stratification, which combined with fibres screening, was identified as a promising alternative, see Figure 16. Trials were performed applying screening to a small part of the production allowing separation of coarse fibres from fine fibres. Production parameters were kept constant in term of refining and the properties of the products were compatible with existing material. This result was also demonstrated in pilot trials.

The fine fibre enriched fraction was considered to be an ideal material for placement on the top of the hardboard. In order to demonstrate this, two separate mats were manufacturing using a second forming machine. One of the mats was made with coarse fibres and a second mat with fine fibres. These mats were assembled before prepressing and drying. These boards had a smoother surface on the top and unnoticeable difference on bottom compared to reference samples. Thus it was clearly demonstrated that surface quality was improved thanks to stratification and optimised use of fibres with limited changes of the process, see Figure 17. Mechanical strength was the same or even improved considering compared to the reference sample.

Finally, hardboard has very limited resistance to water, resulting in swelling. This is due to their composition, which is exclusively wood and with no additives. As previously described for MDF, chromatogeny treatment was applied in order to reduce hydrophobicity of hardboards, which would expand their use. This resulted in an improved water repellence and better resistance to swelling over time. Processing conditions were fully compatible with such a treatment, requiring the installation of a module to the existing line.

All these solutions were compatible one to each other, making it possible a cumulative improvement of process and boards as defined in the FMC. They all proved to be transferred at mill and demonstrated during full mill-scale trials. Of these results only chromatogeny requires further development.

Tools for evaluating the impact

Within the BoostEff project several tools have been developed that has been used in order to assists the development and in the evaluation of the impact of the results.

Development of a generalised simulation environment

As a key point in the project the possibility to evaluate the effect of the new future manufacturing concepts towards project goals has been addressed. The starting point was to define the requirements regarding raw material quality, process performance and product quality i.e. boundary conditions to develop the future manufacturing concept. In order to do this work was performed with the target of developing a platform assisting the work defining these concepts as well as evaluating the impact.

To support the generalisation and further exploitation of the BoostEff modelling approach, a simulation environment has been set up by generalising the developed methodology and complementing it with additional elements. Thus a Generalised Simulation Environment (GSE) was developed that lends itself for supporting technology developers and decision makers when evaluating future technological process options.

Furthermore the models have been developed to explore the technical features of the future manufacturing concept. Their calibration is based on information derived from the process owners of the future manufacturing concept and the key technology providers and further inputs provided by the work focused in environmental impact. Thus the GSE uses the knowledge gained within BoostEff as a baseline and has been used within BoostEff for evaluation.

The structure of the GSE is shown in **Error! Reference source not found.**8. The essential modules of the Generalised Simulation Environment include the process models and the product models. The process models capture the driving elements of the entire production processes as well as the newly introduced key technologies (FMCs) in order to calculate material and energy efficiencies as well as costs. Suggestions for an optimised process setup with respect to the key targets can be inferred.

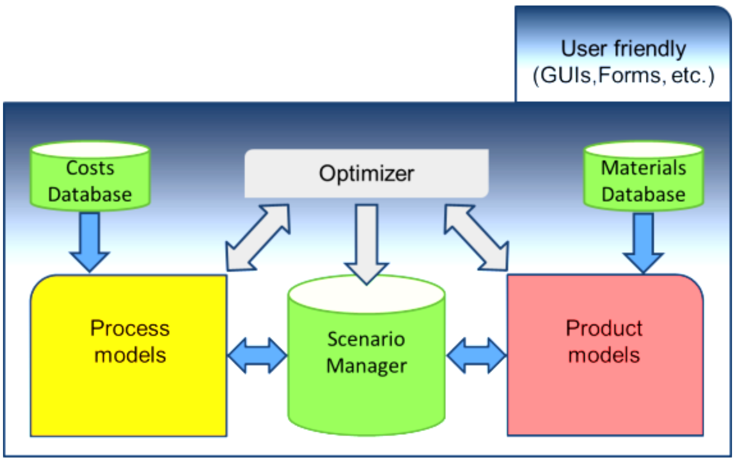


Figure 18. Elements and structure of the Generalised Simulation Environment

The models are complemented by databases and user interfaces. Additionally, optimisation algorithms are available. As to experience, their benefit for identifying technological optima is rather limited, as it is not possible to cover all relevant process parameters and effects that technology experts would consider – including qualitative effects – within the models. The preferred method of optimum identification is running scenarios and evaluating them in cooperation and discussion with technology experts.

The Material and cost databases

The Material and cost databases stores and provides material constants of raw materials and the costs of relevant process factors respectively. Based on this information, alternative material compositions can be simulated and evaluated against current structures and costs for manufacturing.

The process models have been developed to evaluate the material, energy and costs effects of future manufacturing concept the impacts on project. For this purpose different FMC options can be implemented as so-called scenarios in the process models and then stored in the scenario manager. An example can be seen in Figure 19, which outlines the workflow. The models are based mainly on first-principles, as energy conservation and mass conservation. Few additionally data-based functions have been implemented. The balancing boundaries set up for evaluation at the production level effects comprise the full paper production line from log treatment to paper finishing. This includes power plant and waste water treatment plant.

The production lines are divided into respective sub-processes. Resource streams are fuels, materials (e.g. logs, pulp, chemicals, paper and rejects), power, heat (steam) and effluent. An example of a simplified schematic view can be found on the right part of Figure 19. The models are set up in Microsoft Excel including Visual Basic macros and balancing tools.

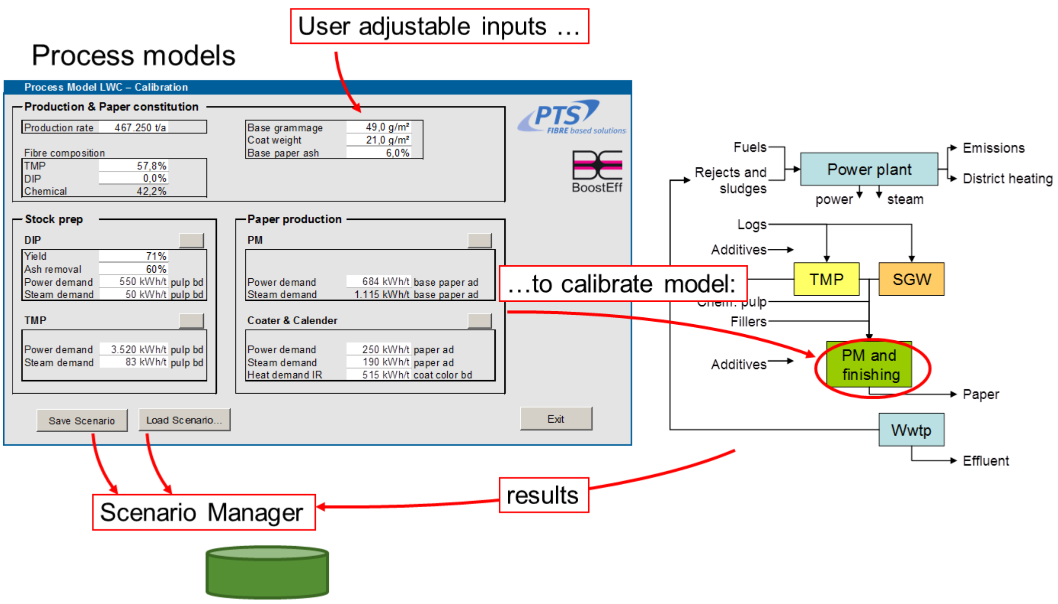


Figure 19. Process model workflow

All calibration data used is introduced as specific values except for the production rate. The costs calibration is based on prices provided by process owners and market inquiries. Costs are assigned as specific values to all input and output streams of the model. The sum of costs is taken as variable production costs. As first principles are being applied, the predictions are judged to be reliable and robust.

Product models

Product models are used to predict various mechanical and optical product properties of layered paper and board products. They allow for comparing between mechanical and optical properties of current monolayer materials and multilayer materials created by applying Future manufacturing concept. Product models play a major role in the optimisation of product properties of new materials and suggest raw material and process settings already during the early design phase.

In general, the models perform mappings from a set of inputs to a set of output values. Due to the BoostEff modelling approach the inputs are vectors consisting of suspension or process parameters. The developed models allow for predicting mechanical and optical paper properties after application of stock preparation and sheet forming transformations, see Figure 20. There is no a-priori restriction in regard to the type of models, i.e. they can be purely data driven (so-called black-box models), purely physical (white-box models) or in-between (grey-box models).

As a part of the product models the fundamental physics has been used. The SC- and LWC-product models developed within BoostEff are thus so-called grey-box models; their behaviour is determined by the implemented physical relationships. These are simplified and real world effects are superposed by additional complex effects. The effects are captured in the model by parameters that have to be inferred with appropriate methods (i.e. data mining). Model calibration has to be performed in order to achieve results as close as possible to real-world measurements.

Several product models for SC- and LWC-paper have been set up. They meet specific requirements defined by the teams working with their concept. Single-layer product models have been built for the SC-FMC to capture the specific modified stock preparation processes and predict the quality of paper made from TMP and SGW. Furthermore, a multi-layer model developed allows for defining a material mix in each of the layers.

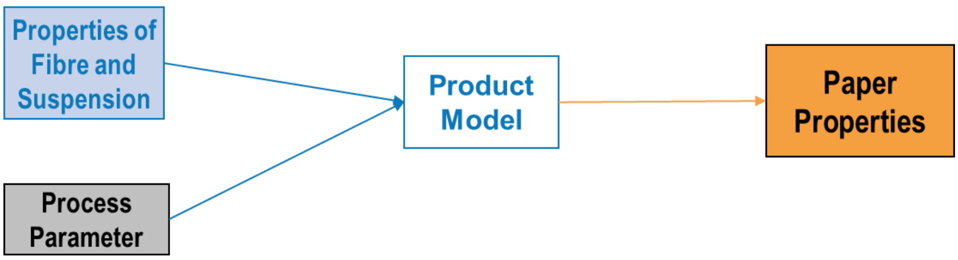


Figure 20. Principle of property prediction by product models.

For the LWC-manufacturing concept similar multi-layer models have been developed that capture the modified stock preparation processes considered. Figure 21 shows examples of graphical user interfaces (GUI) from single-layer and multi-layer models. Finally, a simplified multi-layer simulation tool with a web interface has been implemented. The tool is designed to exemplary demonstrate some of the features of the prediction tools that has been developed within the scope of BoostEff project. It is accessible at the following link, http://shpoint.ptspaper.de:8080/BoostEff/.

In order to model the behaviour of MDF and hardboard the models for paper could not be used. Therefore model for these products was developed separately but it can still be integrated in the GSE as well.

Scenario Manager

Both types of models, i.e. process models and product models, allow for exporting their simulation results into a Scenario manager. A table based representation permits easy visualisation and thus effective comparison of different scenarios and optimum selection. Scenarios are extracted from and exported to the Scenario Manager. Finally, the optimum solutions are determined in the scenario manager by evaluating the various scenarios with corresponding process knowledge. The scenario manager allows presentation of results in various ways in order to support the evaluation procedure, e.g. as line charts to visualise scenario distinctions, see the example in Figure 22.

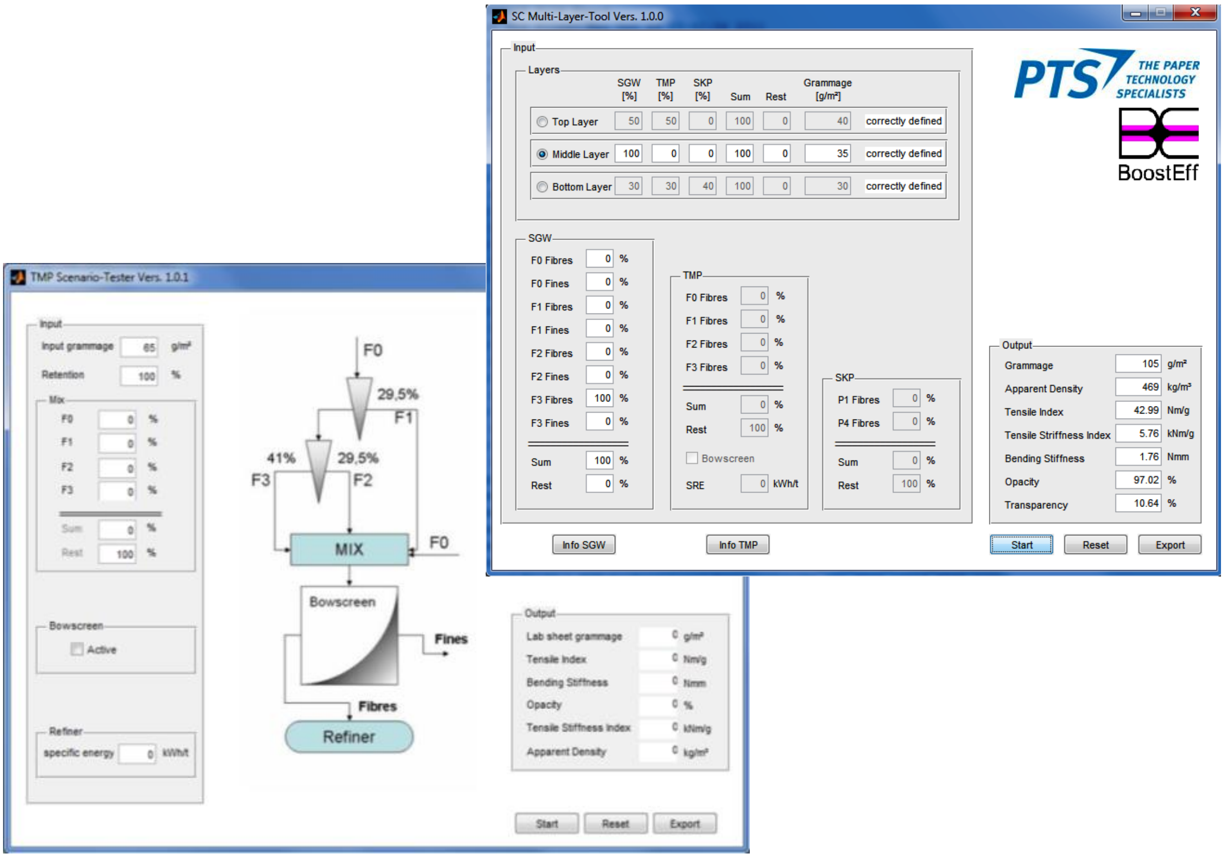


Figure 21. GUI of a single-layer (bottom-left) and a multi-layer (top-right) product model for SC-paper.

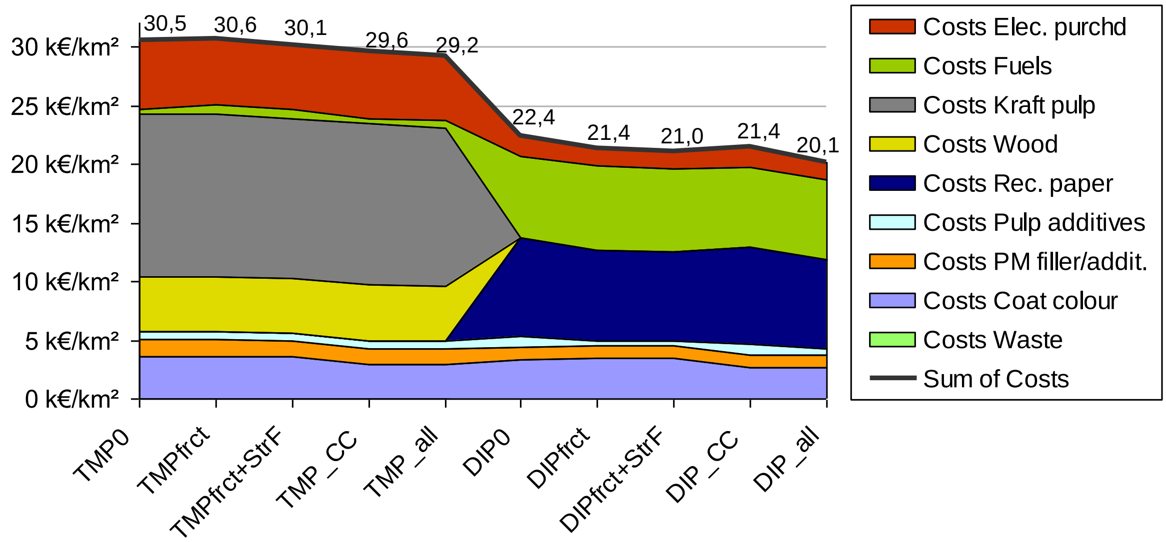


Figure 22. Changes in costs and cost structure **for different scenarios.**

The future use of the GSE

The Generalised Simulation Environment with integrated process models and product models is available for further implementations. The BoostEff models are ready for application, i.e. they introduce the future manufacturing concept to further applications in respective industry sectors. In case the considered processes equal those analysed within BoostEff, a direct applicability is given. Since the GSE provides models for SC and LWC papers as well as for MDF and hardboard, a wide variety of potential application cases is guaranteed.

In cases in which the process under consideration is structural different from BoostEff example processes a structural adaption has to be realised together with a modeler. This can be done with limited effort. Figure 23 sketches this situation.

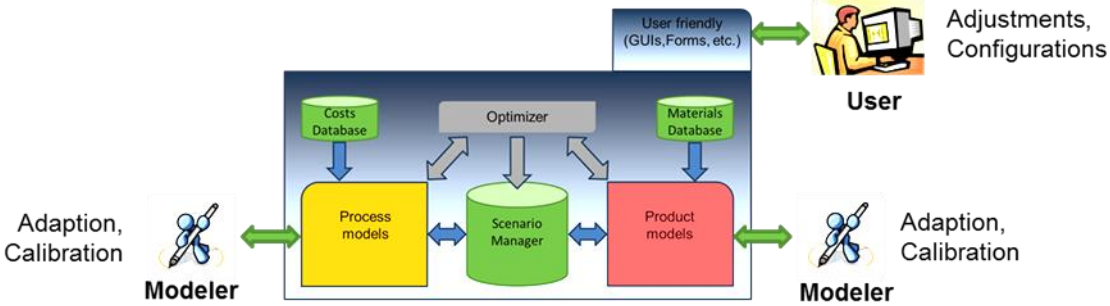


Figure 23. Use scenarios for the Generalised Simulation Environment**.**

Use of the process and product models developed within BoostEff supports a target oriented and cost-efficient control of process adaptions towards future manufacturing concepts. The results of simulations suggest process modifications already during the early design phase without need of cost-intensive full scale trials. The GSE allows for a comparison between the target parameters of existing process chains and promising new approaches. It is possible to efficiently evaluate the existing technical and financial options a mill has. Improvements are possible by exclusion of suboptimal process modifications after calculation and evaluation of different scenarios. The promising process modifications become visible and can be included in a future manufacturing concept. Product models are used to observe the impact of process modifications in regard of product quality. With their help a comparison between optical and mechanical properties of existing products and the outcome of a modified process chain is possible. Especially the differences in optical and mechanical properties of monolayer and multilayer materials can be evaluated. By calculating various scenarios, main drivers for improved process settings can be deduced as well as optimum scenarios with regard to the key parameters covered. In cooperation and discussion with technology expert, optimum business cases then can be identified.

Taking all this into account, use of the Generalised Simulation Environment developed within BoostEff offers great potential to assist comprehensive improvements of manufacturing processes for fibre based materials.

Potential impact

Methodology for evaluating the impact on the project targets

The individual goal for each future manufacturing concept was to demonstrate that it is possible to reduce the environmental footprint and increase the competitiveness. With this objective it was seen as imperative to identify and develop and accurate and transparent methodology to do the evaluations towards the targets. The methodological approaches defined for the assessment of the BoostEff targets were to be able to quantify:

- an energy efficiency increase by 20%
- raw material savings by 20%
- reductions of emissions of CO_2 and other greenhouse gases by 20%
- operating cost reduction by 10% or productivity by 10%

Regarding quantification of an energy efficiency increase by 20%

For the energy efficiency evaluation a gate-to-gate approach was chosen. It means that, although the energy efficiency analysis considers the savings within the sub-processes in which the future manufacturing concept have impact, a gate-to-gate approach from the total process of paper/board making is reported and considered for the BoostEff target assessment. All the energy consumptions in the processes are referred to the functional unit selected, that is, 1 m^2 of paper/board produced with and without the future manufacturing concept. A description of the system boundaries consider for the energy efficiency evaluation is presented in Figure 24.

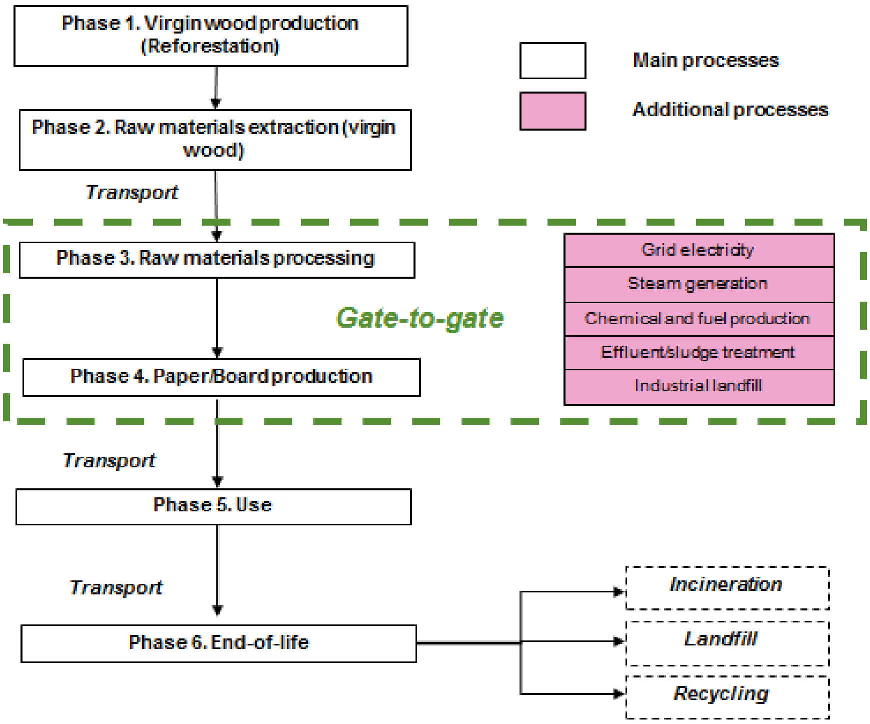


Figure 24. Description of the gate-to-gate approach considered to assess energy efficiency.

The evaluation of the energy efficiency of each of the future manufacturing concept is based on the data obtained by the energy balancing and simulation tool that was developed. Therefore, the energy usage figures for both conventional and the new proposed concepts are obtained by that tool and validated by industry partners. The reference cases for conventional production are primarily based on the chosen production units of the industrial partners. To ensure a high significance for industry the evaluation of energy efficiency with respect to the mill energy demand is considered (gate-to-gate approach). The datasets were thoroughly checked against benchmark values to ensure representativeness. Thus the results are transferable to other industrial plants. In addition, as described in a previous section the process simulation models are based on first-principles –energy and mass conservation- so that they can be rated as robust and reliable. Remaining inaccuracy has to be attributed mainly to the up-scaling of results from lab and pilot scale. The formula to evaluate the BoostEff target of energy efficiency increase was:

$$\%\ \text{Energy efficiency increase} = \left\{ 1 - \left(\frac{\sum \frac{\text{MWh of energy consumption}}{\text{m}^2\ \text{of FMC product}}}{\sum \frac{\text{MWh of energy consumption}}{\text{m}^2\ \text{of conventional product}}} \right) \right\}\ \text{x}\ 100$$

Regarding raw material savings by 20%

Regarding the assessment of raw material savings, the mass balance model was complemented with a cost analysis of the raw materials used to produce the paper/board product in each case. As described in the BoostEff project description the primary focus is the use of forest resources primarily and total raw materials secondary. All the raw materials used are referred to the functional unit selected, that is, 1 m^2 of paper/board produced with and without the future manufacturing concept. The selection of the functional unit in an area base it is important for the assessment of raw material savings since reduction in grammages (g/m^2) is expected for the new future manufacturing concepts of the paper products. The system boundaries are again set in a gate-to-gate approach, the same than in the energy efficiency evaluation.

The evaluation of the raw materials savings of the future manufacturing concepts will be based on the data obtained by the balancing and simulation model developed. Therefore, the raw material figures for both conventional and future manufacturing concept production are obtained in WP3 and validated by industry partners. The scope to be considered for the raw material savings evaluation is a gate-to-gate approach. The formulas to assess the BoostEff target related to the raw material savings in terms of mass were:

$$\%\ \text{Raw material savings (in kg)} = \left\{ 1 - \left(\frac{\sum \frac{\text{Kg of raw material}}{\text{m}^2\ \text{FMC product}}}{\sum \frac{\text{Kg of raw material}}{\text{m}^2\ \text{of conventional product}}} \right) \right\}\ \text{x}\ 100$$

And in terms of costs:

$$\% \text{ Raw material savings (in €)} = \left\{ 1 - \left(\frac{\sum \frac{\text{€ of raw material costs}}{\text{m}^2 \text{ of FMC product}}}{\sum \frac{\text{€ of raw material costs}}{\text{m}^2 \text{ of conventional product}}} \right) \right\} \text{ x } 100$$

Regarding the reduction of emissions of CO_2 and other Green House Gases by 20%

The standard to be considered for carbon footprint assessment is the **ISO 14040-44 Life Cycle Assessment**. Other standards were also consulted as additional information such as the draft of ISO 14067 "Carbon footprint of products" or the ILCD 2010 International Life Cycle Data Set. The evaluation of the carbon footprint of the future manufacturing concepts compared to the baseline scenarios are based on the data about the energy and raw materials savings obtained by the process and product modelling tool and validated by industry partners. Figure 24 represents both the cradle-to-gate and the cradle-to-grave approaches to be considered for the Carbon Footprint assessment.

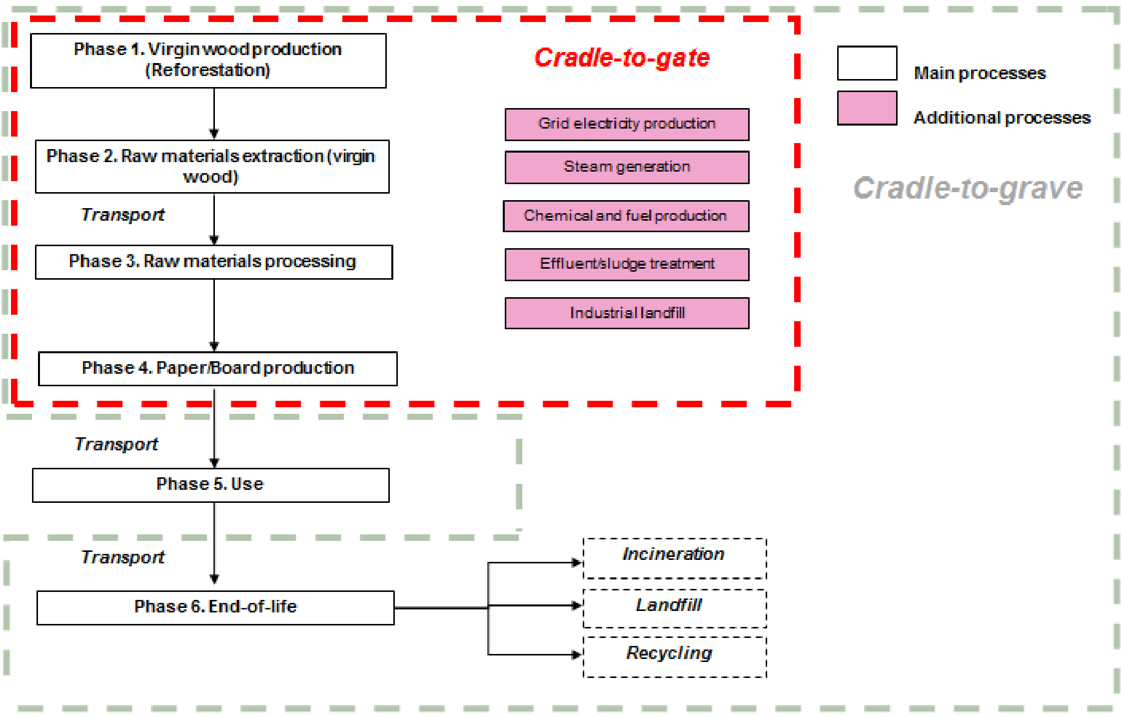


Figure 24. Cradle-to-gate and cradle-to-grave approaches to assess carbon footprint.

The formula to assess the BoostEff target related to the reduction of carbon footprint was:

$$\% \text{ Carbon Footprint reduction} = \left\{1 - \left(\frac{\sum \frac{\text{KgCO}_2\text{eq.}}{\text{m}^2 \text{ of FMC product}}}{\sum \frac{\text{KgCO}_2\text{eq.}}{\text{m}^2 \text{ of conventional product}}}\right)\right\} \text{ x } 100$$

Operating cost reduction by 10% or productivity increase by 10%The scope to be considered for the costs analysis is a gate-to-gate approach, that is, the same than considered for energy and raw materials assessment since costs of energy and raw materials inputs are included within the assessment. All the costs to be considered are referred to the functional unit selected, that is, 1 m^2 of paper/board produced with and without the future manufacturing concept. Data obtained by the process and product modelling tool regarding the energy and raw material savings are used to estimate the operating costs reduction. Reference data for costs of energy consumption and raw materials was given by industry partners and European average data from published sources. Costs inputs considered for the analysis of the BoostEff targets are mainly raw material costs, energy demand or employee salaries. Additionally, other aspects such as the investment and amortization required for the implementation of future manufacturing concepts at mill scale in comparison with the conventional mills are also reported in order to evaluate the business case for the new future manufacturing concepts developed within the BoostEff project. The formula to assess the BoostEff target related to the operating cost reduction was:

$$\% \text{ Operating costs reduction} = \left\{1 - \left(\frac{\sum \frac{\text{€ of total costs}}{\text{m}^2 \text{ of FMC product}}}{\sum \frac{\text{€ of total costs}}{\text{m}^2 \text{ of conventional product}}}\right)\right\} \text{ x } 100$$

Considering the productivity increase, then the formula would be:

$$\% \text{ Productivity increase} = \left\{\left(\frac{\sum \text{earnings FMC mill (€)}}{\sum \text{ earnings conventional mill (€)}}\right) - 1\right\} \text{ x } 100$$

Finally, another important aspect to be considered to demonstrate the business case of each of the future manufacturing concepts developed is the net present value (NPV). NPV can be described as the “difference amount” between the sums of discounted: cash inflows and cash outflows. It compares the present value of money today to the present value of money in future, taking inflation and returns into account. If NPV > 0, it means that the investment would add value to the firm and therefore project may be accepted. This is the way to demonstrate if there is a business case for the future manufacturing concepts developed for the paper and board products. In addition, the Internal Rate of Return (IRR) of the future manufacturing concept investment has been calculated.

Apart from the assessment of the specific BoostEff targets an overview of environmental footprint best practices in the pulp and paper industry has been made. This background information was important to know the considerations made by the industrial partners for the development of the different future manufacturing strategies. In particular, the aspects of energy efficiency, raw material and emission savings are highlighted (see Figure 6), and the core questions related to the carbon footprint issues addressed here are as following:

- General environmental footprint best practices used today in the state-of-the-art production processes at pulp and paper mills

- Future manufacturing concepts production processes at the pulp and paper mills that will have the largest potential for the improvement of environmental footprint

In particular, current investigation is a literature review of the Best Available Techniques (BAT) that presently are exploited by the pulp and paper mills (BREF 20012, BREF 20123) and future scenarios of forest fibre industry that is represented by pulp and paper and wood-based products (CEPI 2011[4]).

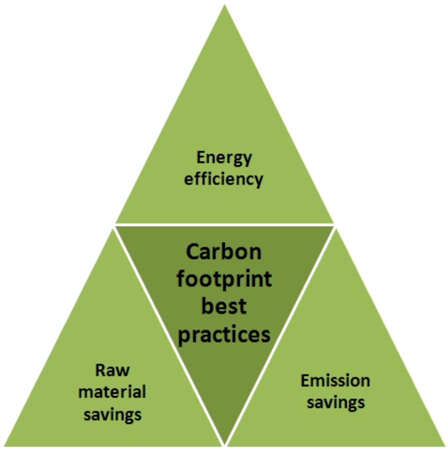


Figure 27. The important components of the environmental footprint best practices, involving work towards energy efficiency, raw material and emission savings.

[2] Integrated Pollution Prevention and Control (IPPC). Reference Document on Best Available Techniques in Pulp and Paper Industry, December 2001, Best Available Techniques (BAT) Reference Document for the production of pulp, paper and board industry. Draft. May 2012, http://eippcb.jrc.es/reference/BREF/PP_D2_0512.pdf, accessed at: 2012-06-18, accessed at: 2012-06-19
[3] Best Available Techniques (BAT) Reference Document for the production of pulp, paper and board industry. Draft. May 2012, http://eippcb.jrc.es/reference/BREF/PP_D2_0512.pdf, accessed at: 2012-06-18
[4] Unfold the future. The Forest Fibre Industry. 2050 roadmap to a low-carbon bio-economy, European Pulp and Paper Industry , CEPI 2011

Evaluated impacts

Towards the BoostEff targets

With the developed methodological approach, the results obtained for the different future manufacturing concepts can be seen summarized in Figures 25 and 26.

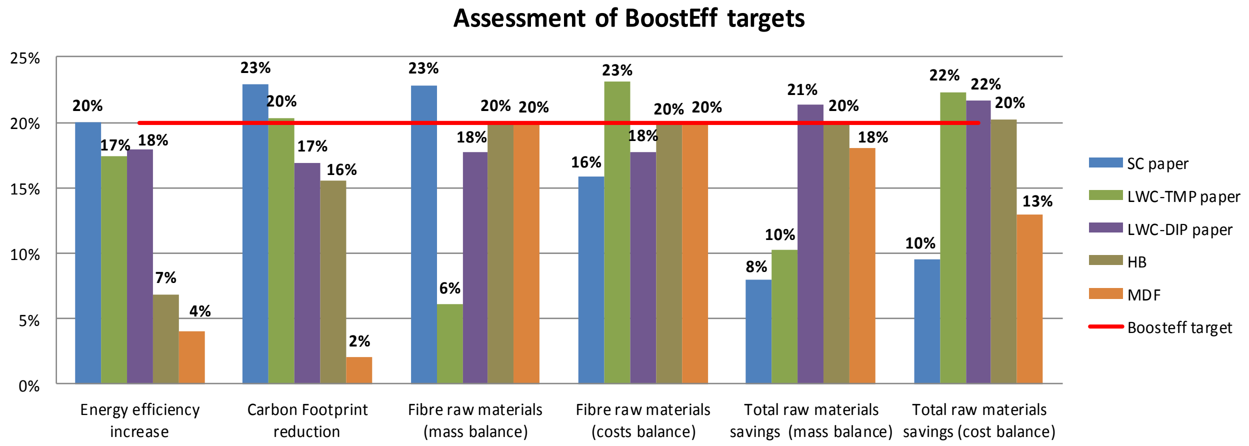


Figure 26. Environmental assessment of the future manufacturing concepts compared to the baseline scenario.

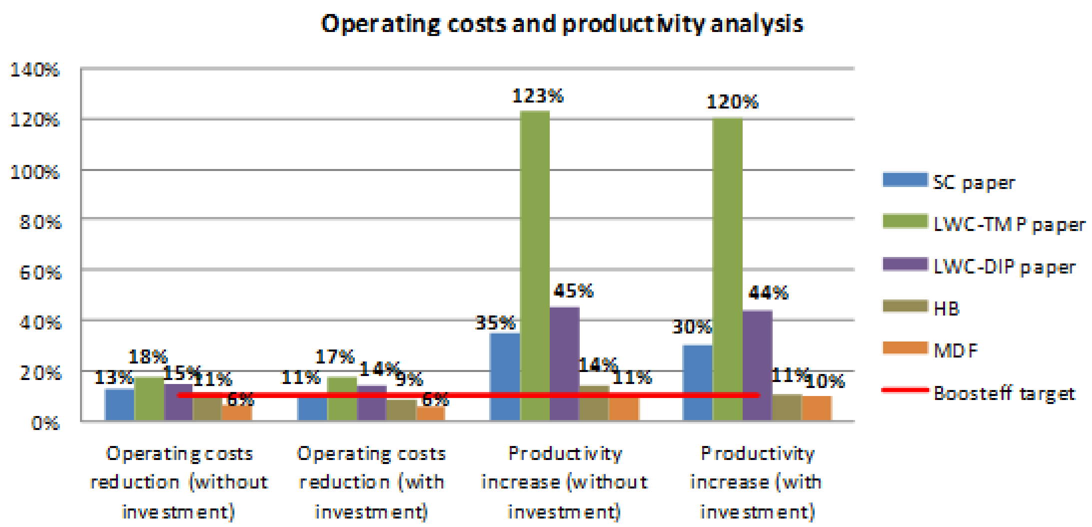


Figure 27. Results of the operating costs and productivity analysis of the future manufacturing concepts compared to the baseline scenario.

From the figures it is clear that most future manufacturing concepts represent significant improvements compared to the baseline. The main conclusions of the analysis have been the successful improvements of the future manufacturing concepts, not only in terms of the environmental targets established (energy efficiency, carbon footprint and raw materials) but also in the economic objectives related to the operating cost reduction and productivity increase of the future manufacturing concepts. Regarding the specific targets of the project these are summarised in Table 2.

	Energy	*Greenhouse gases*	*Fibre raw material*	*Productivity/Operating costs*
SC-paper	20%	23%	23%	30% / 11%
LWC-paper (DIP)	18%	20%	18%	44% / 14%
LWC-paper (TMP)	17%	20%	23%	120% / 17%
MDF	4%	2%	20%	10% / 6%
Hardboard	7%	17%	18%	11% / 9%

Table 2. Summarised results towards the BoostEff targets.

At this point, it is also important to highlight that despite not all the BoostEff targets have been achieved, in general terms the improvement potential of the future manufacturing concepts is even bigger. Standard (reference) operating conditions are well known and have been identified during long industrial operation whilst the new technology has not yet been subjected to optimisation. When implemented the end effect (better than pilot-scale) would be reached after some time in mill development/optimisation.

The chosen future manufacturing concepts have had the sole purpose of meeting the targets of the BoostEff project, but within the project other combinations have been identified that were shown to have other uses. Apart from the impacts on the pre-defined project targets the main part of the suggested future manufacturing concepts offer a high degree of flexibility when it comes to what type of products could be obtained and how to make the best benefit of these. Thus it is possible to tweak the concepts towards e.g. maximum competitiveness, which would be an important task I securing a future for the paper and fibreboard industry in Europe.

Furthermore, an important aspect regarding the potential impact is the willingness to invest in the proposed future manufacturing concepts. In Figure 28 the internal return rate for the suggested concepts can be found. As can be seen all proposed concepts have significant return rates, which would mean that they should be seen as attractive as investments.

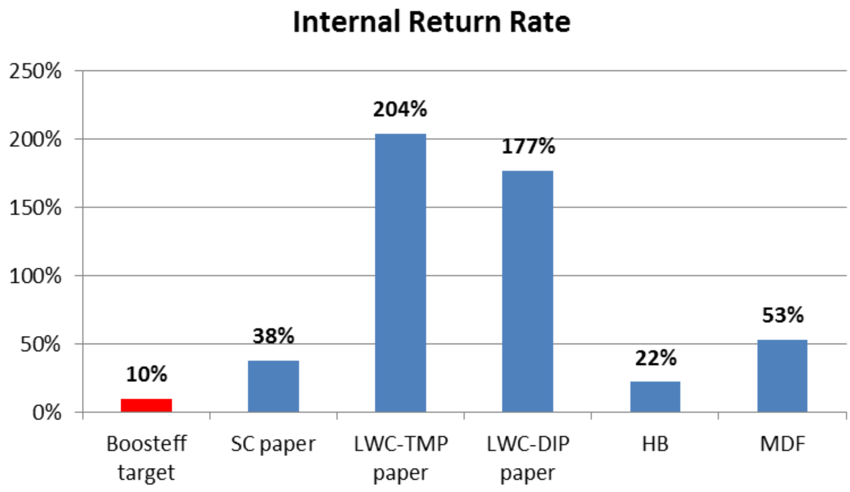


Figure 28. Internal Return Rate (IRR) of the investment of the different FMCs.

Societal aspects

In addition, assessments of societal aspects associated to the future manufacturing products were performed. It was carried out by means of a complete analysis of the markets of these products, considering the improvements made. Moreover, the potential uses of the new products developed were identified. With this information, the analysis of the customer acceptance of the products produced by the future manufacturing products was completed. The acceptability of these products has been compared to the baseline situation. The main results of the customer acceptance study are presented in Figures 29 and 30 as well as in Table 3.

These results rank the importance of the results obtained. There are clearly differences between hoe the different products will be seen. Regarding the paper products the carbon footprint is ranked as number one. For SC-paper this is followed by the brightness of the product and the fibre raw material reduction as number three. For LWC-paper the reduction in energy demand is number two, followed very closely by the amount of additives used.

Regarding the MDF and hardboard the ranking is clearly different. Most important are product properties with surface homogeneity coming out as the number one priority. The effect on greenhouse gases, energy demand and use of fibre raw material ends up in the bottom of the table.

Finally, a multi-criteria analysis was developed and applied to the future manufacturing concept products, in order to compare current and future products from an environmental, economic, social and technical point of view. As previous results indicate, the products compare favourably to the baseline products according to the different perspectives analysed regarding technical, environmental and economic. The results are summarized in Figure 31.

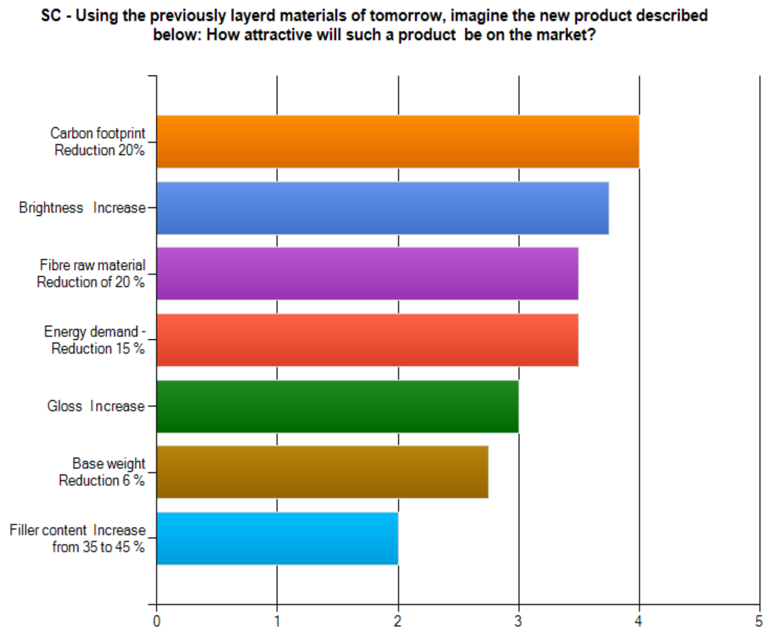


Figure 29. Rated importance of improvements achieved in SC-paper.

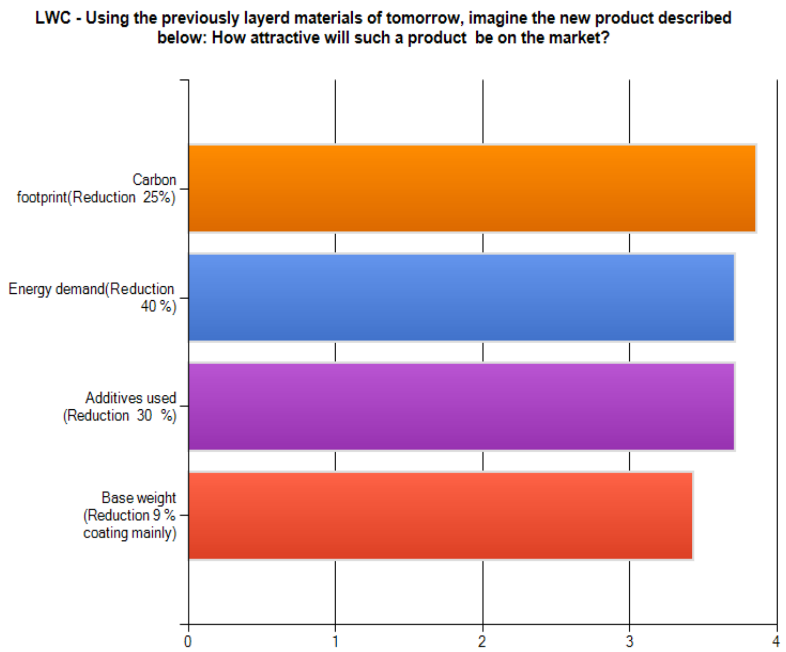


Figure 30. Rated importance of improvements achieved in LWC-paper.

FMC Improvements	Importance to MDF (mean)	rank	Importance to HB (mean)	rank
Surface homogeneity (Increase)	3,50	1	3,40	1
Resistance to humidity (Increase)	3,00	2	3,00	2
Density (Reduction)	2,67	5	2,80	3
Strength (Increase)	2,83	3	2,80	3
Fibre raw material (Use of recycled fibres or sludge)	2,00	6	2,60	4
Process energy (Reduction)	2,50	6	2,60	4
Carbon footprint (Reduction)	2,80	4	2,40	5
Formaldehyde (Reduction)	2,33	7	-	-

Figure 29. Results of customer acceptance study: Rated importance of improvements in MDF and HB.

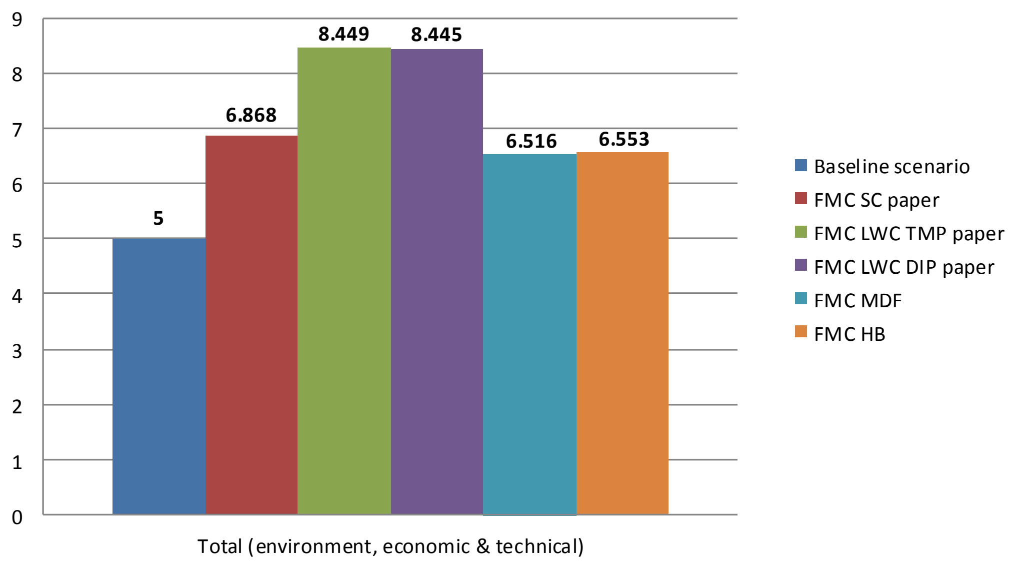


Figure 31. Rated importance of improvements achieved in LWC-paper.