Impact Analysis in a European Cooperative Research Project: A Case Study

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***Abstract*—The European cooperative research project 3D-LightTrans addresses the need for affordable lightweight components in the automotive sector by establishing a manufacturing chain for the industrial production of glass/thermoplastic composite parts with deep draped textile reinforcement based on a novel approach. In this paper, an ad-hoc methodology is proposed to realize the impact assessment of the project. The preliminary results of the impact study are presented and discussed, justifying how the project will contribute to a significant technological progress in composites manufacturing and to a very large economic benefit, as well as to a decrease in the CO_2 footprint of cars.**

***Index Terms*—impact study, composite manufacturing, lightweight materials, automotive parts**

I. Introduction: The 3D-Light Trans Project

Lightweight materials have strategic importance in the transport sector, since the fuel consumption and CO_2 emissions are directly related to the weight of the vehicle. However, their widespread adoption is hindered by technological and economic constraints.

In this context, polymer composites with textile reinforcement constitute a promising alternative, as they combine the lightweight and low cost of plastics with the superior properties of the reinforcing material (like glass or carbon fiber), while woven fabric reinforcement leads to higher performance and enhanced material properties. However, commercial applications of textile reinforced polymer composites (TRPCs) are still restricted to few cost intensive, small series niche markets. This is due to the complexity and lack of flexibility in the processing, combined with too slow and expensive existing manufacturing processes.

The European cooperative research project 3D-LightTrans addresses this issue by developing a low-cost manufacturing technology for high-performance, lightweight TRPC parts in the automotive sector. A simplified representation of the process is shown in Fig. 1: in a novel approach, multi-material semi-finished fabrics made of hybrid yarn are shaped to deep draped pre-fixed multi-layered and multifunctional 3D-textile pre-forms. These are then efficiently processed into the final composite part by thermoforming.

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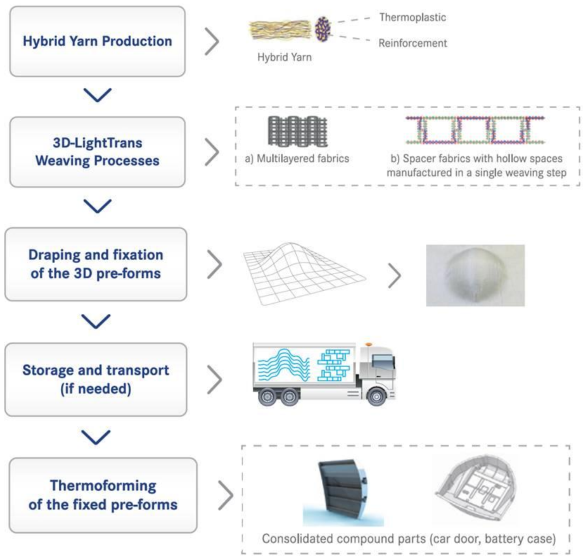

Figure 1. The 3D-LightTrans composite manufacturing chain

3D-LightTrans is a very promising low-cost alternative for the manufacture of light-weight structural components in the automotive sector. Similar to light-weight parts produced with other technologies, 3D-LightTrans components –made out of plastic and fiber glass- weight much less than their steel counterparts. However, the real breakthrough enabled by this project is actually related to the manufacturing processes and is twofold: Firstly, a great improvement in the properties and performance of the final composite parts has been achieved, in comparison with other glass reinforced plastic composite technologies. On the other hand, the optimized manufacturing procedure allows for fully automated manufacturing with an important cost reduction. This makes an alternative for cost efficient parts with good enough properties to allow its use in structural parts for the automotive sector [1].

The project is implemented by a European consortium of 18 partners from industry, research and academy (see Fig. 2), who receive public financial support from the European Commission. Xedera is responsible for the realization of an impact study, which is complemented by the Life Cycle Analysis (task in progress by Centro Recerche Fiat, Grado Zero Espace and Austrian Institute of Technology) and by the market analysis (performed by Austrian Institute of Technology).

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Figure 2. The 3D-LightTrans consortium

A preliminary rough analysis of the expected impact was done at the project preparation phase, considering the state of the art at that time and estimates for the expected performance of the technology to be developed. Three years later, with the project approaching the finish line, there is a need for a deeper reflection on the real impact that the project will have, in the light of the results achieved till now, the current situation and state-of-the art.

In answer to this need, an impact study is elaborated within the project. Firstly, the case-specific aspects of the 3D-LightTrans technology as subject of the impact study needed to be reflected in the definition of its purpose, scope and audience. A thorough analysis of relevant aspects and techniques for impact studies in general, as well as those with applicability in publicly funded, technology related research projects was then performed. A methodology for the realization of the impact study has been developed, which uses a selection of the techniques identified in the previous phase. The methodology proposed is applied to the subject of the study (the 3D-LightTrans technology) and gives some relevant initial results and conclusions. This paper reports on the complete process described in this paragraph.

The rest of this paper is organized as follows: In the introduction, the scope, purpose and targeted audience of the study are defined. In section II the methods are described, including the general methodology and a brief introduction of specific techniques used. In section III the results are presented and discussed. Section IV summarizes the main conclusions and further work.

II. Definition of Scope and Purpose

A. Scope of the Study

In an impact study research is done on a certain topic to determine if a certain action would, or is, having some sort of an effect on its environment or other related issues. A similar, more specific and much more frequently used term, is “impact assessment”. The International Association of Impact Assessment (IAIA) defines *impact assessment* (IA) as the process of identifying the future consequences of a current or proposed action [2].

The oldest, most well-established aspect of IA, is Environmental Impact Assessment (EIA), which is defined by IAIA as “the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made”. In this context, impact analysis (the process of identifying and predicting the likely effects of the proposal) and environmental impact statement (the final report documenting the impacts, proposed measures for mitigation, significance of effects and others), are defined as a part of the EIA process. Impact assessments can also cover social, economic, health, cultural and biodiversity aspects, among others. The expression *Integrated IA* is sometimes used when different forms of impacts are covered, whereas the term Sustainability Assessment is also used by some professionals, referring to the integration of the environmental, social and economic dimensions of assessment. [2]-[3].

In this document, we will use the term impact study to refer to the analysis of the technological, economical, *and* environmental impact of the project 3D-LightTrans. The actual subject of the study is the 3D-LightTrans technology- currently in its last phase of development- for the manufacturing of lightweight composite parts. We will constrain our analysis to the impact linked to the manufacturing and use of structural parts in the automotive sector, like the tailgate and spare wheel well demonstrated in the project by Centre Recherche Fiat and Bentley, respectively. We aim to address the impact from a two-fold perspective. On one hand, we address the impact of the introduction of the 3D-LightTrans industrial manufacturing technology, considering the complete supply chain. On the other hand, we also reflect on the impact of introducing parts manufactured with the 3D-

LightTrans technology in the vehicle fleet (thus reducing the weight in comparison with steel and/or decreasing the price in comparison with other more expensive light-weight technologies).

B. Purpose and Targeted Audience

Irrespective of the topic under investigation and of the chosen nomenclature, the first step in any impact study or assessment is to define its purpose and scope. Generally speaking, the aspects covered, level of detail and scope of an IA depends strongly on the topic subject to analysis, the institution or body preparing it and the objectives pursued. For national or European legislation initiatives, the impact assessment can give decision-makers evidence regarding the need for an action and the advantages and disadvantages of alternative policy choices. In the humanitarian sector, impact assessment can be concerned with making judgments about the effect on beneficiaries of humanitarian interventions, and constitute an integral part of Monitoring and Evaluation frameworks [4]. Impact analysis of commercial goods and services is often done in the context of economic and environmental sustainability, but it can also include social and socioeconomic sustainability aspects, as discussed in [5]. IAs for commercial products and services may give evidence for suppliers, manufacturers and service providers in favor of a given procedure, specific choice of material and product properties, manufacturing technology and process location, among others.

The assessment of impact in publicly funded research projects may have aspects in common with one or more of the impact study types discussed above, but also has many distinguishing aspects. To define the purpose and audience of the 3D-LightTrans impact study, we need to take into account the industrial character of the project, concerned with industrial manufacturing. The sectorial aspect also plays a role, namely in the transport and, more specifically, in the automotive sector. Last but not least, we have to consider that the subject of analysis is a technology under development in the frame of publicly funded cooperative research project. In the light of this, we define purpose of this study as follows:

To inform decision making and result in appropriate levels of economic benefit, environmental protection and community well-being, decision makers can be: a) persons at a higher management level within the participating companies, b) potential customers and c) other stakeholders. Within the participating companies, the impact study is expected to provide sufficient, reliable and usable information to plan in which way to go ahead with the exploitation of the project results. It can also help in the planning of additional research activities or to decide whether the technology should be modified or applied to other products in a future. Potential customers are provided with arguments to make informed decisions on the appropriateness of the 3D-LightTrans technology for a specific product, depending on the specific requirements, economic constraints and environmental aspects. Other stakeholders (e.g. technology platforms, public authorities and funding bodies) can take the impact study results into consideration when drafting research programs or developing technology roadmaps, for example.

To provide a tool for project monitoring and evaluation by the project consortium itself and report to the funding authority on the progress towards the project objectives and their associated expected impact. The impact study results in an iterative and adaptive process, which can be adjusted to the reality of the research results. It can also be adapted to take into consideration the evolution of other relevant technologies, normative or other issues appearing during the life-time of the project, which may influence in the project impact. The process should result in information and outputs which assists the consortium, if necessary, with problem solving and may consider the development of mitigation measures to avoid negative impacts, as well as the monitoring of their efficacy.

To supply information of interest to communicate with the general public, providing arguments which justify the advantage and usability of the research results, the purpose is both to increase awareness and to demonstrate the benefit of the work funded with public funds (ultimately paid by the tax-payer).

III. Methods

A. General Methodology

There is no standard methodology which can be universally applied to assess the impact of any science and technology research project. Therefore, an ad-hoc methodology has been established for the 3D-LightTrans study, making use of elements commonly applied to the different types of impact assessment discussed in the previous section. The methodology proposed pulls data from all appropriate sources and looks at all aspects of relevance. Its main process steps are described next:

1. Scoping- to identify the issues and impacts that are likely to be important and the level of detail required and to define the alternatives against which 3D-LightTrans is compared. Here, we assume that structural vehicle parts will to some extent continue being produced from steel, but light-weight materials will be increasingly introduced, including light metals and composite materials using other technologies.

2. Use of research and performance indices or indicators as the project evolves. The indicators are computed from the comparison between baseline data at a given point of time and baseline data previous to the project (initial baseline), in order to assess the degree of project progress resp. of achievement of goals. This information will be crucial to estimate the real technological impact of the results achieved. The specific data assigned to the indicators are calculated using the most appropriate method on a case-to-case base (e.g. laboratory testing of material samples, manufacturing chain simulation results on the base of a hypothetical scenario, nominal values for machine performance provided by the equipment manufacturers, etc.)

3. Collection of additional information from literature review, expert opinions, available databases, feedback from other project tasks (LCA, marketing) and other sources. This provides relevant background information

and additional input data for establishing comparisons with other state-of-the-art technologies and for providing a holistic view.

4. Impact analysis-to identify and predict the likely effects of the project results in the technology, environment and economy, and to evaluate the importance of the findings. This analysis is done on the basis of the information retrieved and collected in the previous steps.

5. Mitigation and impact management (if applicable), proposing measures to prevent or minimize adverse impacts or any obstacles detected which could hinder the fulfillment of the expected impact.

6. Preparation of the report. Final conclusions are drawn and the main statements on the project impact are listed in the final report.

The techniques to be used in the second and third phase have been selected after evaluating different types of techniques applicable in impact studies. A complete list can be found in [6] and includes, among others, case studies, checklists, expert systems, indices or indicators, laboratory testing and scale models, literature review, matrices, monitoring, qualitative and quantitative models (conceptual), risk assessment, scenario building and trend extrapolation. The most relevant techniques used in the 3D-LightTrans impact study are briefly introduced next.

B. *Indices or Indicators and Monitoring*

Quantitative and qualitative indices or indicators can be used to measure the results and progress of a project as it evolves. In research projects, research and performance indicators may be defined in such a way as to enable an assessment of the degree of achievement of the impacts associated to the project objectives. For example, in the service contract "IEE Project Performance Indicators" (EACI/IEE/2011/001), *impacts* are defined as identifiable changes which demonstrate the extent to which the project activities have an effect on the target group, and can take place during its lifetime (specific or short term impacts) or beyond its lifetime (strategic or long term impacts). The use of performance indicators is recommended to determine the success of the project in reaching its objectives and creating energy related impact [7].

In the 3D-LightTrans project, research and performance indicators are stated in terms of percentage of reduction, degree of improvement, grade of enhancement, etc. of the actual values (measured at a specific point of time) of technology related baseline data in comparison with the initial baseline (baseline data at the beginning of the project or value known or estimated for state-of-the-art comparable processes). The baseline data defined in the 3D-LightTrans project to provide measurable means to assess the work progress are stated in terms like processing time and yarn displacement, among others.

The initial baseline (where the project work starts), and the corresponding value of baseline data to be determined at a specific point of time for assessing the progress in the project, are obtained from diverse measurement objects at the different stages of the project lifetime, namely:

1) Different test pre-forms, during the development phase, as those shown in Fig. 3.

Figure 3. Tetrahedron pre-form for draping tst (left) and thermoforming tools for profile pre-form (right)

2) Final demonstrations objects, during the demonstration phase (see Fig. 4)

Figure 4. Bentley's spare wheel well (links) and CRF tailgate

C. *Life Cycle Analysis (LCA) and Carbon Footprint*

Product environmental life cycle analysis (LCA) is used for identifying and measuring the impact on the environment of industrial products, including not only the effect on climate change, but also other impact categories, such as acidification potential and ozone depletion potential [8]. These EIAs consider technological activities used for various stages of the product: extraction of raw material for the product and for ancillary materials and equipment, through the production and use of the product, right up to the disposal of the product, the ancillary equipment and material.

A Carbon Footprint, also called Carbon Profile, is an LCA with the analysis limited to carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions (e.g. methane, laughing gas, etc.)[9].

IV. Results and Discussion

A. *Scientific and Technological Impact*

In this section, we outline broadly the progress beyond the state of the art achieved so far in the project, and the breakthrough that this represents (technological impact):

Concerning *modeling and simulation*, the main outcome is a comprehensive simulation toolbox. The breakthrough here is that the toolbox covers the whole manufacturing, process related, material and product simulation aspects of the textile reinforced thermoplastic composite technology in a holistic approach. The toolbox possibilities begin with the micro-scale properties of the glass fibre and thermoplastic fibre, cover the meso-scale modeling of the dry fabric architecture and simulation of the drapability and of the thermopressing process, and end up with the micro-scale homogenization of the consolidated hybrid yarns and macro-scale modeling of impact behavior of the thermoformed plate (see Fig. 5). An additional module is devoted to the modeling and simulation of the complete process chain.

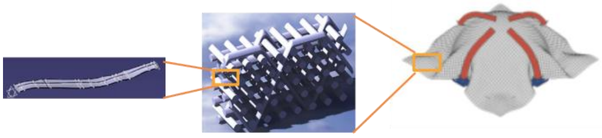

Figure 5. Micro-, meso- and macro- modeling: from the yarn to the textile preform

This result has a crucial direct impact in the up-scaling capability of the 3D-LightTrans technology for industrial manufacturing: It provides a key tool for easing the redesign of the entire automotive supply chain with regards to materials, product design, and process design, which is a vital need and one of the major challenges which contribute to hinder the wide-spread introduction of light-weight materials in the automotive sector.

Hybrid yarn, composed of reinforcement material (glass) and thermoplastic matrix (see Fig. 6), is manufactured in the 3D-LightTrans project by air co-mingling, a technique which delivers the best impregnation behavior. The main outcome of this task is the modified equipment for industrial manufacturing of hybrid yarn, implemented in PD-Glasseiden Oschatz making use of the process knowledge developed in cooperation with TU-Dresden.

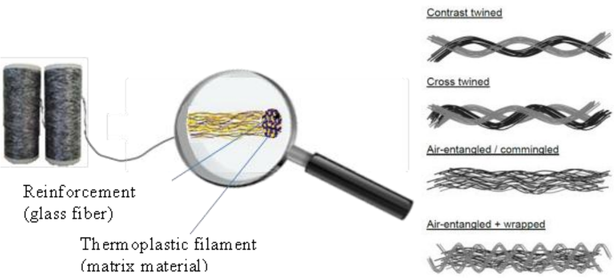

Figure 6. 3D-LightTrans air co-mingled hybrid yarn, integrating thermoplastic matrix material and glass fiber reinforcement

Although hybrid yarn integrating glass fiber reinforcement with thermoplastic matrix is not a new technology and some types of it are commercially available, 3D-LightTrans results go beyond the state of the art in that improved performance and higher repeatability have been achieved with a variety of compositions, while the yarn is optimized to minimize the abrasion damage during multilayer and spacer fabrics weaving, and the highly homogeneous distribution of material guarantees good performance of the final 3D-LightTrans composite. The key impact is, therefore, the success in satisfying the demanding requirements linked to the further processing of the resulting commingled glass/PET yarn with the 3D-LightTrans manufacturing chain, which effectively qualifies the resulting parts for its use in structural vehicle components.

Multilayer and 3D-shaped weaving: Two modified weaving machines have been delivered in the project, with contribution of TU-Dresden and the equipment manufacturers Dornier and Van de Wiele, respectively. Multilayer fabrics have been produced with Z-reinforcement in different orientations, which improve the delamination behavior and the out-of-plane properties especially in 3D stress and impact loading, for the first time, with thickness up to 1 cm (see Fig. 7, left). Further, spacer fabrics with outer layers connected by crosslink fabrics can be industrially produced –also for the first time- in a single step (see Fig. 7, right). The innovation and progress beyond the state of the art are linked to the 3D-LightTrans capability for industrial production of more complex weave architectures and thicker fabrics with a large degree of flexibility, keeping reduced fibre damage and guaranteeing highest quality final product quality.

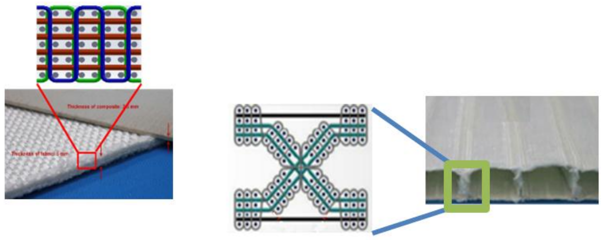

Figure 7. Multilayer fabric with Z reinforcement (left) and cross woven spacer fabric (right)

Figure 8. Automated draping (Leitat, Promaut)

Draping, fixation and final consolidation: 3D-LightTrans approach to increase the efficiency of the forming and consolidation steps consists in decomposing the procedure in several parts. In the pre-fixation step, a local increase of mechanical stiffness is achieved in well-defined areas previous to the draping, whereby special fibers with modified characteristics are integrated and processed using alternative heating methods. Automated draped, as shown in Fig. 8, can take place either in a dummy tool or in the thermoforming tool. Here, a special draping device is attached as end-effector to a robot, which is subsequently programed to follow a given trajectory, while the fabric is kept in place by clamping/holding devices. Alternative strategies are evaluated through drapability simulation, and the draping process is supported by force control. A fixation of he shaped dry fabric in its final 3D geometry (without consolidating the composite) takes place by means of thermal activation and/or application of additional binders. After fixation, the increased stiffnes allows to storage and transport the draped fabrics without deforming them. The final composite part is consolidated by thermoforming. In this process, the thermoplastic melts and flows among the glass fibers, while the press creates a strong compaction of the fabric (above 50%).

The table below gives a summary of baseline data and performance indicators by now:

TABLE I. BASELINE DATA AND PERFORMANCE INDICATORS

Baseline	Initial/reference baseline	Current baseline data	Performance indicator
Hybrid yarn manufacturing speed	Not available for the chosen glass/PET composition	500 m/min	Not applicable
3D textile properties	Thickness < 1cm No woven spacer fabric	Thickness>1cm Woven spacer fabric	Higher structural variety achieved
Geometrical stability during storage/transport	Not stable	Stable	Fixation achieved
Composite forming process time	With RTM 1 hour = 3600 s	230 s. to 510 s.	>80% reduction
Fibre displacement in the thermoformed part	> 1 mm	< 0,5 mm.	>50% reduction

B. *Impact in the Natural Environment*

The impact in the natural environment is addressed by means of the Life Cycle Assessment (LCA), a dedicated project task with contributions from CRF, GZE, AIT and (as regards the interfaces with the impact study) Xedera. This task is in progress and the final results are not yet available. In this section, we discuss broadly the most relevant aspects and foreseeable results.

Energy and carbon footprints: Here we consider both the contribution to the footprint of both car manufacturing and car service. Using known data on industry emissions by sector, we reach for car manufacturing a footprint of 720 CO_2 per £1000 (around 17 Tons for a Ford Mondeo with medium specifications). Of this amount, 33% corresponds to metal extraction (for a Ford Mondeo with medium spec., 5, 61 Tons). A second major contribution to the car manufacturing footprint is related to the gas and electricity used by the automobile industry itself, including all the component manufacturers as well as the assembly plant, and it accounts for 12% (around 2 Tons for a Ford Mondeo with medium spec) [8], [9]. The 3D-LightTrans technology has some aspects that could decrease the manufacturing footprint of cars in several ways, e.g. by reducing the footprint associated to obtaining raw material, by using lower temperature processing (in comparison with metals) and avoiding the need for low temperature storage and transport of pre-forms (in comparison with thermoset composites). However, other contributions would add on in the energy consumption balance, like those of the fabric weaving and automated draping. More details on the Life Cycle Analysis of the 3D-LightTrans manufacturing chain will be provided in the LCA report towards the end of the project.

The environmental impact of the project is also related to the abatement of CO_2 emissions through vehicle weight reduction, which is a key aspect justifying the large potential of composites in supporting long-term development of the automotive sector, according to [10]. Using yearly average data for passenger vehicle (cars, minivans, pick-ups, vans and SUVs), we come to an average footprint of 0, 1954 Kg CO_2/Km [11]. Assuming 100.000 Km/vehicle, this means 20 Tons CO_2 per vehicle during its entire lifetime. The reduction of the mass of a single structural component in 2 Kg. using 3D-LightTrans technology would mean, if we assume a linear relationship between CO2 exhaustion and the vehicle's weight, a decrease of the order of 32 Kg. CO_2 per vehicle for its entire lifetime. If component is integrated in only one thousand part of the cars produced in a single year throughout the word, this could lead to a reduction of CO_2 emissions of between 1.000 and 2.000 Tons. Further, if the 3D-LightTrans technology is generalized and used for manufacturing other components, in the long term we could be speaking of an abatement of many thousands Tons CO_2.

C. *Economic Impact*

A detailed analysis of economic aspects is addressed by Austrian Institute of Technology in a dedicated project task, devoted to market analysis and business cases. In this section, we will discuss from a general perspective the expectable economic impact in terms of material costs, manufacturing costs and added value.

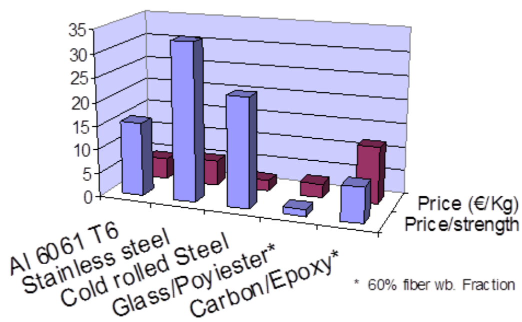

Figure 9. Comparison of indicator price/strength for different materials

Material costs: If we consider the indicator price/strength, compared for different materials in Fig. 9, we can conclude that glass/polymer materials composites constitute a very cheap option in comparison both with steel and with other light-weight solutions. However, the mechanical behavior of glass/polymer based composites is generally speaking worse, which restricts the range of potential applications of this material in transport. With the 3D-LightTrans technology, we achieve an improvement of the properties of the glass-thermoplastic composite which brings it to the level required by structural automotive components. In this way, our technology can comply with the needs of products which required till now the use of more expensive materials, in order to become lightweight. To provide an idea of the potential economic impact, we assume the price of a glass-carbon-epoxy composite could be reduced in 75% if it was produced in glass/PET using 3D-LightTrans technology. For an automotive component with a medium to large volume of parts manufactured per year, this could lead to annual savings in the order of magnitude of several millions.

Manufacturing costs: Improved properties of glass/plastic composites can be achieved with different processes, from braiding or conventional weaving with autoclave to structural reaction injection molding (SRIM). However, the production costs and/or required investment are higher than with 3D-LightTrans, as illustrated by the estimated cost distribution shown in Fig. 10.

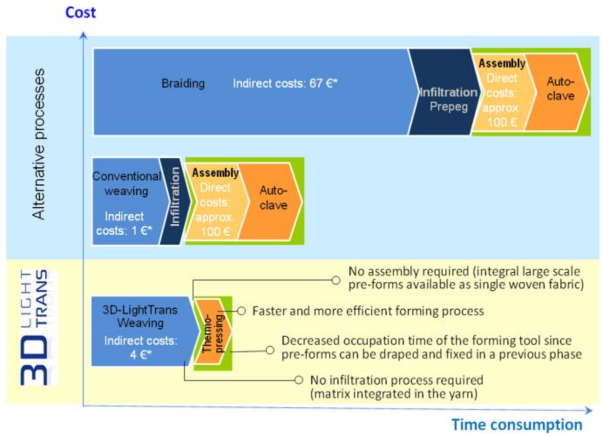

Figure 10. Comparison of estimated costs for 3D-LightTrans and other alternative processing technologies

Added value: The economic impact can also be related to the added value which the 3D-LightTrans technology brings. By enabling the manufacturing of more complex structures in one piece (e.g. by weaving thicker textiles instead of using sandwich structures with thin fabrics) the material properties can be significantly enhanced. The use of automation for draping will lead to higher repeatability and an increase in quality. Another example of added value is the potential to extend the functionality of the parts produced with the 3D-LightTrans technology, e.g. by integrating cabling or ventilation channels within parts made with spacer fabric.

V. Conclusions

In this work we have presented an ad-hoc methodology and the current results of an impact study within 3D-LightTrans, a research project devoted to the development of a manufacturing chain for low-cost, high performance automotive composite parts. The paper shows that the proposed methodology is appropriate for the assessment of technological, environmental and economic impact of European cooperative research projects with an industrial background.

Although the impact study is still on progress, the main aspects of the foreseeable project impact have been outlined and discussed. Beyond the large technological impact of the research performed and the expected contribution to decrease the CO_2 footprint of cars, also the economic benefit is remarkable. In the light of these results, we can conclude the project 3D-LightTrans will have a huge impact by making textile reinforced composites affordable for mass production of structural car parts, fulfilling increasing requirements on performance, light weight and added value of the final product with a competitive price.

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Seibersdorf research, where she established and led during several years a successful research group for Micro- and Nanohandling and -integration. Since 2008, she is company owner and Manager of Xedera e.U., a technology consulting enterprise based in Austria. She has more than 50 scientific publications and several contributions to science and technology books. Her main previous research interests include manufacturing, micro- and nanotechnologies and intelligent systems. Today, additional fields of interest and activity are concerned with knowledge management, impact studies, exploitation, communication and dissemination within EC cooperative projects. Dr. Almansa has received several awards for her work, including the 2nd prize of the 2005 Austrian Research Centers Award in the Category Science, the Profactor Group Award 2007 and the Best Session Presentation Award in the IEEE ICIT Conference. For several years, she was also member of the jury in the Austrian prestigious Leonardo Award to the best automation solutions.