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MARKET PLAN OF RECYCLED CARBON FIBERS AND FINANCIAL ANALYSIS OF A CASE STUDY IN THE AUTOMOTIVE INDUSTRY

RT/2023/4/ENEA

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Abstract

This work refers to research activities carried out within the REcycled carbon fibres for high VALUE composites – REVALUE Project, founded by EIT RawMaterials and performed in the period 2017-2019. All the information and data here reported are referred and updated to this period. The main goal of this document is to provide an insight into the market for carbon fibers reclaimed from end-of-life composites. It identifies market outlets for recycled carbon fibers (rCFs) in various industrial sectors, in particular the Automotive, with the aim to investigate potential applications in which the new material would enter as a competitor of components based on metallic materials or polymers reinforced with glass fibers. The following pages will show that thermoplastic compounds reinforced by high value rFCs are the best compromise to changes imposed in the automotive sector, in order to produce structural, sub-structural and accessories components in the automotive industry.
In addition, a clear and wide documented analysis of the EU market scenario and market plan of this specific segment in the automotive field will allow justify the possible investment in composite reinforced with recycled carbon fibers.
On this basis, the study continues with the deepening of a Case Study: a 7-year long accurate financial analysis of the market introduction of an innovative thermoplastic compound reinforced with rCFs is developed, aiming to evaluate the feasibility of trade of this typology of composite material.

Key words: *Recycled carbon fibers, Automotive, Thermoplastics, Market analysis, Financial analysis.*

CONTENTS

1. BACKGROUND SUMMARY

In the industrial sector of transport media, it has already been accomplished a massive employment of composite compounds reinforced with CFs (Carbon Fibers) for several requirements (environmental, social, international political agreements and higher fuel efficiency), particularly for environmental aspects which call for a further cut by 2020 of CO_2 emissions to 20% below the 1990 levels [EU-28].

From the economic side there is the challenge of recovery expensive long carbon fibers (68 €/kg for aerospace grade fibers, and 17-25 €/kg for commercial grade) at their end-of-life, into commercial grade applications, as it already happens in the automotive field for some virtuous car-makers (once for all the BMW example). Carbon Fiber Reinforced Polymers (CFRPs) structures weigh half that of steel counterparts and one-fifth less than aluminum ones.

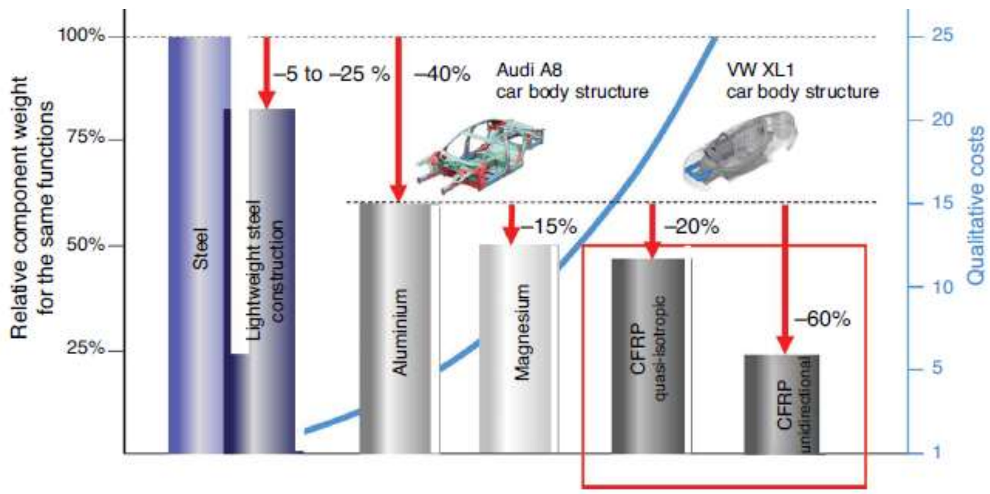


Figure 1: Weight losses for different materials (steel, aluminum, magnesium, CFRPs quasi- isotropic and CFRP unidirectional).

Light weighting advantages are also found in comparison with the cheaper Glass Fiber Reinforced Polymers (GFRPs). Despite the benefits of using CFRP, composites nowadays cost significantly more than GFRPs and also more than metal components, even allowing for lighter weights.

Figure 2: Comparison between a green and grey world by the use of lightweight vehicles and alternative energy fonts.

The high prices have so far limited their use to high-performance vehicles such as jet fighters, spacecraft, racecars, racing yachts, exotic sports cars, and notably, the latest Airbus and Boeing airliners. The major costs are determined by carbon fibers in the composites. They come from the so-called Polyacrylonitrile precursors (PAN), which constitute the 50% of the cost of the fiber; the remaining costs are determined by a series of thermal treatments, needed to stretch, polymerize and carbonize the PAN fibers and various post-processing stages helping to ensure their durability and "handeability"

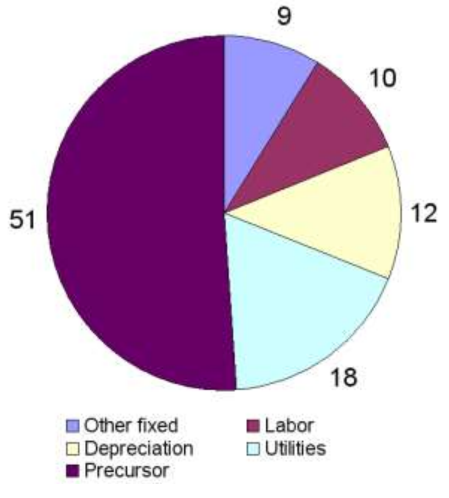


Figure 3: Apple pie cost percentages of rCFs.

The recovering of CFs from high performance CFRPs (such as those derived from aircraft cemeteries) by thermal processes (*pyrolysis*) allows to dissolve the polymer matrix and to obtain recycled Carbon Fibers (rCFs), with mechanical properties similar to virgin CFs. Pyrolysis ensures environmental costs saving linked to avoided landfill of scraps or wastes of CFRPs and to obtain cheaper rCFs thanks to overcoming the cost due to PAN. Employing past competences and results at laboratory scale, one of the main goals of REVALUE Project was to scale-up the sizing process for recovered rCFs (chopped fibers) to restore the original coating present on the virgin long-sized carbon fibers. This is strategic goal to valorize the rCFs from pyrolysis at best. Secondly they would like to obtain thermoplastic composites (using Polypropylene (PP) and Polyamide6 (PA6) commercial and recycled polymeric matrices) reinforced with sized recycled fibers, for automotive uses. At the end of the Project, the OEM Company of REVALUE – Fiat Chrysler Automobile (FCA) – has been in charge to produce a demonstrator among four selected parts of a car and using both types of polymers.

A clear and wide documented analysis of the EU market scenario and market plan of this specific segment in the automotive field will allow to justify the possible investment in composite reinforced with recycled carbon fibers.

2. STATE OF THE ART

Although the GFRPs are the material of choice for approximately 95% of all composites, the European GRP market is not growing as rapidly as the composite industry in other regions of the world (i.e USA, Japan and China). In the global market, Europe is destined to decline. Some stringent necessity are prevailing on the GRP market [1]. Nowadays it is very important to have the possibility to use materials at low environmental impact, with less CO_2 and greenhouse gas emission released in the atmosphere, and reducing at the same time the necessity of primary sources, maintaining high quality levels. In the automotive industry it is particularly significant because of industry's changing needs. In the go-to-market paragraph it will be clarified the increasing pressure onto European automotive industry to meet several requirements in a pre-fixed medium term period (2018-2020): higher fuel efficiency, environmental targets imposed by normative dispositions and international agreements. All these faces of the same medal contribute to firmly stick European car-maker Companies to reach European standards. High Carbon Fiber costs, long CFRPs manufacturing life cycles times and uncertain CF supply are among the primary reasons why the use of CFRPs by automotive industry has remained confined to ultra-expensive, low production volume models [2]. A new age for CFRPs employment was began in 2013 when BMW start selling the i3 electric vehicle [3]. It is a virtuous example where three simultaneous goals are reached:

1) a significant amount of CFRP was used so that the final mass of the car was 1195 Kg;
2) a significant number of new cars was produced in that year: 30,000 units/y;
3) a remarkable number of customers were allowed to buy them because the price point was popular enough (about 40,000-45,000 $ USD).

The core of the i3—quite literally—is its CFRP Life Module, which allowed cutting the costs of the material's manufacture and of its application in automotive production, with reduced cycle times but without quality degradation. Although no precise details are given by BMW, production cycle times have been cut by a further 30% for the i3 compared to the M3 model, in which CFRP was applied only in the roof production. Assessing shorter times of processes, it was possible to halve the production costs. For structural vehicle components CFRP presents major light weighting opportunities, giving place to vehicles 30% lighter than aluminum and 50% lighter than steel. Reducing the production costs can be achieved recycling disused CFRP components, containing virgin fibers, solving at the same time the problems correlated to waste disposal [2,4].

Polymer composites reinforced with recycled carbon fibers (rCFRPs) are widening their range of applications in the field of transports. In fact the actual volume of production equal to 20,000 MT for 2017, is expected to increase at 100,000- 140,000 MT for the year 2020 [5-7].

Despite the great opportunity offered to the market by rCFRPs from waste or end-of life products, it is not adequately reciprocated because of a series of difficulties to overcome. Generally, the main reason can be understood simply recap the current status of recycled carbon fiber materials. Today, recycled products exist in forms that are suitable for use by compounders (milled and chopped fibers in powder or pellet form) and in composite layups, (nonwoven mats as dry fabrics as well as pre-pregs and sheet molding compound materials). However, the use of these products outside of R&D projects is very limited. The major barriers are the lack of knowledge about mechanical properties and processing characteristics of these new materials, and the lack of large-scale demonstrators that prove the economic, technical and environmental justification for using them. A certain number of projects are addressing these issues, but the push from the *manufacturing side* of the supply chain to find a solution to its carbon fiber waste problem generally is not matched by a pull from the supply chain's *design side* to find ways of using recycled carbon fiber products [3,4]. In other words, there is a gap between supply (from the design side) and demand (from the manufacturing side) to fill. Moreover, it would be vital that all elements of a supply chain work closely together not only to develop methods of recycling carbon fiber, but also to get recycled carbon fiber products back into the supply chain, giving life to closed-loop recycling solutions. According to lifecycle assessments (LCAs), the production of virgin carbon fibers has a significantly higher impact on the environment than competitor materials such as steel and aluminum. Recycling routes for these metals are well established, whereas methods for recycling carbon fibers have only become commercially viable very recently. BMW is the only car-maker in Europe using CFRP in anything approaching high volumes. It is also the only car-maker currently using a closed-loop process for recycling dry carbon fibers at scale. Finally and perhaps most significantly, BMW is using secondary fibers in thermoplastic granulates for injection molding applications, and is starting to employ these materials in the manufacture of parts for vehicles produced by its other brands. These parts were previously produced using a polyamide (PA) reinforced with glass fibers at a loading of 30% by weight. Working with thermoplastics specialist Akro-Plastic and interiors manufacturer Grammer, the carrier is now made from a PA reinforced with scrap carbon fibers from the i models at a loading of 10% by weight. The part is not only 15% lighter that its glass fiber-reinforced counterpart, it is also significantly stronger and stiffer. Crucially, it can be produced using the same injection molding equipment at the same price.

From an economic standpoint, recycled carbon fiber products can reduce the cost of light weighting, used either on their own or in conjunction with virgin carbon fibers. In fact, making light weighting strategies *affordable* must be the primary goal to reach, before increasing the use of carbon fiber in high-volume applications. If we address this challenge, then we can increase the total use of carbon fiber in these developing markets. From the environmental standpoint, reducing waste and reusing materials that have a high-embedded energy, and which can be recycled in an energy-efficient manner, is the right thing to do, from a social responsibility point of view but also to bypass huge problems correlated to waste disposal. Thanks to its economic sustainability and industrial scale technical feasibility, pyrolysis is the only recycling method implemented on industrial scale, yet only negligible amount of waste CFs are actually recycled with this method. In fact currently there are only four SMEs in the world producing rCF by pyrolysis: three in Europe, the other one is in Canada. All these Companies continue to meet strong difficulties in market penetration, due to a combination of causes, yet the main industrial barriers for a massive rCF use as reinforcement of composite materials are represented by the technical limits due to the rCF features resulting from pyrolysis. A number of automotive industries Companies in Europe have developed cost and time-effective solutions to carbon fiber recycling, and an initial range of products are now available for the compounding and composites industries. The time is right for the industry to work together, to move recycling from the fringes to its rightful place, as an integral part of the carbon fiber market. In doing so, it should be improved the cost and the environmental footprint of our businesses, creating additional and sustainable supply chains for critical raw materials, and help the overall carbon fiber composites industry to grow. This is not only a choice but also a need. Legislative requirement in Europe, in the transport sector, impose a short term normative on new vehicles produced. The must should be to recycle extensively following indicative and binding targets related to both GHG emissions (in particular CO_2) and air pollutants (nitrogen oxides, particulate matter emission and hydrocarbons) [7]. All OEMs are tied to the 85% recyclability of the components that make up a car (for both luxury and mass cars). OEMs are therefore forced to modify their production chains, making it easier to recycle their mechanical components. Recycled carbon fiber products are expected to increase their presence in the European market, according to the past estimate of CAGR (compound annual growth rate) from 2010 to 2015 contained in the Composite Market Report 2016 document. An increase of +13% of the production volumes will correspond to an estimated demand of 113,000 tons for rCF in 2020. In particular, Regulation 510/2011 foresees a limit fleet average CO_2 emission from new light commercial vehicles to 175 g/Kg for the period 2014-2017 and 147 g/kg up to 2020. More specifically the EU CO_2 regulation imposes the limits of 130 g CO_2/km (y-2015), 95 g CO_2/km (y-2020) and 20 g CO_2/km (y-2050).

For gaseous air pollutants, the most recent Euro 6 standard normative referred to light vehicles (< 1305 Kg) foresees the 0.5 g/Kg for CO, 0.08 g/Kg for NO_x, 0.17 g/Kg for NO_x+HC in diesel, and for petrol vehicles 1.0, 0.060 and 0 g/Kg, respectively (Regulation 715/2007/EC).

A massive recovery of CFs from wastes is more and more an environmental need and a great opportunity to obtain high value materials at low cost.

Among others car-makers, also FCA is addressing this issue and envisaging the introduction of recycled carbon fibers into production cycles. More in detail the FCA industrial plan in EMEA targets over 2.5 million of vehicles in 2012, including also vehicles that are sold in

US and other transportation sector (trucks, commercial vehicles, etc.). In this work an alternative, innovative CFRP-based component for automotive uses is proposed, for which FCA estimated a market penetration of about 10% of FCA vehicles per year. In particular the proposed component will involve cars applying high quality dashboard that amount to about 50% of the total production, equivalent to the employment on about 150,000 FCA vehicles, reaching 2,400,000 units in 2030 (see TABLE V in "*Business Plan Section*").

3. PRODUCT DESCRIPTION

Within the REVALUE Project it was planned the development of a compound made of 12% of rCFs (chopped like from pyrolysis and then standardly sized) and the remaining part in weight made of virgin PP or PA, which can substitute counterparts commercial products

The Market Plan considers the replacement of glass fiber composites market with recycled carbon fiber composites in the automotive industry, with particular attention to the European market segment (Germany-UK-France). Glass fibers are notoriously cheaper (1 €/kg) than the virgin carbon fiber counterpart (17-25 €/kg for commercial grade) and also very powerful from a point of the performance of a car component. However serious level of mass achieved with GFPs components imposes high fuel levels of consumption and also limited possibility to recycle glass fibers because they lose their mechanical properties. Both limitations, in the EU framework of environmental policy targets and objectives (the 20-20-20 targets approved by the European Council in March 2007 was just the starting point), need to take into account "new" materials with the same safety and performance features but lighter and recyclable.

The thermoplastic compound reinforced by high value rFCs seems to be the best compromise to changes imposed in the automotive sector, in order to produce structural, sub-structural and accessories components in the automotive industry. A general great interest of the automotive industry is devoted to the environmental aspect of car production, taking in great consideration the following aspects for a more sustainable future:

1) the materials employed;
2) the life-cycle of the produced vehicles;
3) the waste management.

4. THE CF RECYCLING CHAIN

The recovering of carbon fibers from high performance carbon fiber reinforced polymers CFRPs by thermal processes, such as pyrolysis, allows to eliminate the polymer matrix and to obtain rCFs. Pyrolysis causes also the burning of the original CF coating ("sizing") so rCFs assume a curved and flaked morphology. Thus, rCFs provide poor mechanical properties to the final composite materials, due to the lack of adequate stress transfer from the polymeric matrix to the reinforcement.

Figure 4: Morphological comparison of chopped fibers.

To overcome this problem, the original sizing present of the virgin CFs must be restored. The sizing treatment, which is tailored for the type of resin that will be used for composite fabrication, is essential to rCF manufacture and critical to several key fiber characteristics that determine both how fibers will handle during processing and how they perform as part of a composite.

Nowadays there is not in Europe a dedicated plant for the sizing treatment of rCFs resulting from pyrolysis. The few rCF sizing treatments are only developed on the laboratory scale and no sizing process is exported to commercial level. The project REVALUE had the objective of exporting from Technology Readiness Level 5 (TRL5) to TRL9 the rCF sizing treatment developed and optimized on laboratory scale in previous projects by Partner CETMA. By the optimization of the rCF surface, it was expected that REVALUE sizing process will make rCFs with the same performances as the virgin CFs, in terms of adherence with the polymeric matrix, manageability and processability during the compound manufacturing by extrusion.

The rCFs may be used as reinforcement of thermoplastic composites to be destined to the manufacturing of semi-structural automotive components by injection moulding. Polymeric materials answering the automotive requirements, in terms of both cost and mechanical properties, will be used as matrix of the composite materials: Polypropylene (PP) and Polyamide 6 (PA6). On the purpose to develop solutions with very high environmental sustainability, the use of recycled PP and PA6 based compounds will be developed as well.

The increasing use of CFRPs in the aerospace, automotive and energy industries suggests a strong increase of the waste of these materials in the coming years, in a regulatory context that will certainly become restrictive in the field of recycling requirement. With the aim to position themselves as leading players in the chain recycling, the REVALUE partners devote much of their resources for the creation of an innovative and efficient CF recycling chain able to provide an answer to the problems above described. The CF recycling chain is discussed in the following paragraphs.

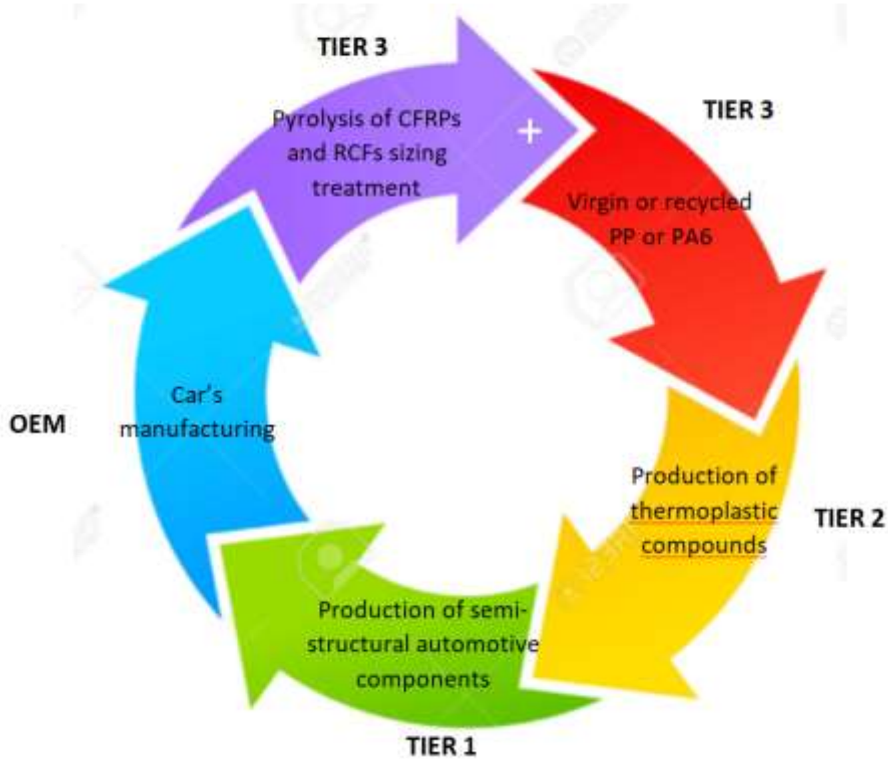


Figure 5: Value chain description.

4.1. Pyrolysis of CFRPs and RCFs sizing treatment (Tier 3)

The thermal decomposition of organic molecules in an inert atmosphere is known as pyrolysis. Thanks to its economic sustainability and industrial scale technical feasibility, pyrolysis is one of the most extensively used recycled process for CFRPs. During pyrolysis the CFRPs is heated up to 450-700 °C in the absence of oxygen. The polymeric matrix is destroyed and the rCFs remain inert and are ultimately recovered. Currently there are only four small and medium enterprises (SMEs) in the world (three in Europe) producing RCFs by pyrolysis. They distribute the recovered fiber as chopped and milled products as well as nonwoven mats. They are:

- **ELG Carbon Fiber Ltd.** (UK) is a subsidiary of German metals recycler ELG Haniel (Germany). This company processes more than 2.000 metric tons of waste material per year in its patented pyrolysis process, including manufacturing waste and cured parts. ELG produces over 1.000 tons of RCF products that can be returned to industry (output in 2015 was just over 1.000 tons).

- **CFK Valley Recycling GmbH & Company** (Germany) is a part of the Karl Meyer Group and it is the Europe's largest composites recycler using pyrolysis. It takes in waste streams from automotive, aerospace and end-of-life sporting goods. It processes over 1.000 metric tons of carbon fiber containing waste each year.
- **Karborek Spa** (Italy) uses a combined pyrolysis and upgrading (in oxygen) patented process to recycle CF and to avoid char formation.
- **Carbon Conversions** (USA) employs pyrolysis and can process the entire composites waste stream. That includes continuous tow from various markets, intermediates — dry fiber waste (from fabrics, trimming, braiding) and "wet" uncured prepreg and pultrusion waste — and end-of-life parts from commercial aerospace, recreational and industrial sources.
- **Carbon Fiber Recycle Industry Co Ltd** (Japan) produces RCFs in a pilot-scale. Details on the process have not been disclosed.

Nowadays, all virgin CF producers formulate their own sizing. On the contrary, rCF manufactures do not treat their fibers with specific sizing procedures. To fill this gap, employing past competences and results at laboratory scale and thanks to the cooperation with the equipment suppliers (such as COMEC), CETMA, ENEA and University of Salento will scale-up (from TRL5 to TRL9) the chopped RCF sizing process and will develop a suitable industrial procedure. During the three years of the REVALUE project, the research partners acquired further know-how on rCF sizing solutions. This can be exploited for publications (or other research activities thereby opening new opportunities) and patents (available for sale or licence). The main idea is to sell in license the optimized sizing procedure to RCF producers as well as to realize a TRL 9 plant for direct industrial use. As previously described, up to now, there is no dedicated plant for the sizing treatment of chopped rCFs so the technology adopted in this project will allow a better valorisation of the reinforcements. The rCFs are discontinuous filaments which require suitable techniques for their handling and moving during the sizing process, different form the technique viable for virgin fibers, where continuous filament rovings feed the facilities used for sizing process.

4.2. Production of virgin or recycled PP or PA6 (Tier 3)

Polymeric materials congruent with automotive requirements, in terms of both cost and mechanical properties, are PP and PA6. In the REVALUE project, they will be used as matrix of the composite materials. In particular, virgin PP or PA6 will be acquired by the most important European suppliers while recycled PP or PA6 will be provided by the partner SUEZ.

4.3. Production of thermoplastic compounds (Tier 2)

By the optimization of the RCF surface modification process, RCFs can be used by CEA and SUEZ (Tier 2) to obtain thermoplastic compounds, using polypropylene (PP) and polyamide 6 (PA6) as commercial and recycled polymeric matrices. In particular, CEA will optimize the compounding process for virgin PP and PA6, SUEZ will do the same for recycled PP and PA6. The produced compounds are semi-finished products. They can be used in several applications, such as the production of semi-structural automotive components.

4.4. Production of semi-structural automotive components (Tier 1)

The produced RCF-virgin or recycled PP and RCF- virgin or recycled PA6 compounds can be used by Tier 1 to manufacture semi-structural automotive components by injection moulding. The thermoplastic compounds reinforced by high value RCFs can be used in place of:

- Virgin CFs reinforced thermoplastic compounds, because the sizing process will provide to RCF performances similar to those of the virgin CFs, with up to 75% of cost saving.
- Glass fibers (GFs) reinforced thermoplastic compounds, thanks to an increasing of the strength/weight ratio of the material.
- Metal components, thanks to an increasing of the strength/weight ratio of the material.

The consequence will be a wider use of CFs in automotive components, with a clear advantage in terms of automotive lightening. There are strong economic, supply chain security and environmental reasons to consider RCFs materials in the search for cost effective solutions for lightening in the automotive industry.

4.5. Car’s manufacturing (OEM)

The end-users of the REVALUE project results are car manufactures. In the project, CRF is the Fiat Group’s major source of expertise in innovation, research and development. It is able to play an active role in the technological growth of the Fiat Group. It will use the semi-structural components in the car's manufacturing process and it will demonstrate the closure of CF recycling chain.

5. EUROPEAN MARKET ANALYSIS

Each year, ACEA compiles the Automobile Industry Pocket Guide in order to provide a clear and complete overview of one of Europe's most important industries: the automotive.
In 2016, EU passenger car production increased by 2.7%, with an overall of units equal to 16.5 million and thus almost reaching pre-crisis levels (y-2009)-ACEA font [8].
Over the past 100 years the automotive infrastructure, and its work force, were focused on metal components, creating barriers to plastic and polymer composites. At the same time the vast number of specialists in materials' composition and processing techniques, within polymers and plastics fields, created barriers to addressing major results collaboratively. Recognizing the pressing needs to improve the environmental impact and to reach high fuel efficiency at competitive costs, the automotive and polymer/plastic composites industries are trying to work together in a new strategic framework for collaborative progress. The automotive industry is crucial for Europe's prosperity. In the first place the automotive industry has an important dragging role in steel industry, chemicals, and textiles, as well as in ICT, repairing, and mobility services. Secondly the sector provides jobs for 12.6 million people (including personnel involved in direct or indirect jobs activities, related to the field) corresponding to 5.7% of total EU employment. In 2016, 18.4 million of commercial vehicles were manufactured worldwide and in particular for the same year Europe produced 86.0% of passengers cars, corresponding to 22.090 units for all geographical areas including Turkey and CIS respect to other types of vehicles, as reported in the figure below and the explaining legend.

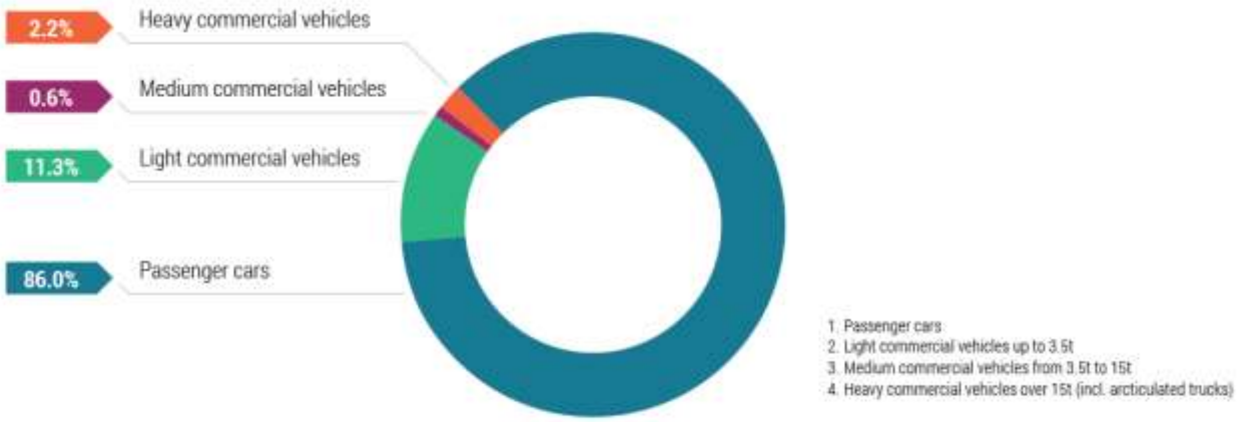
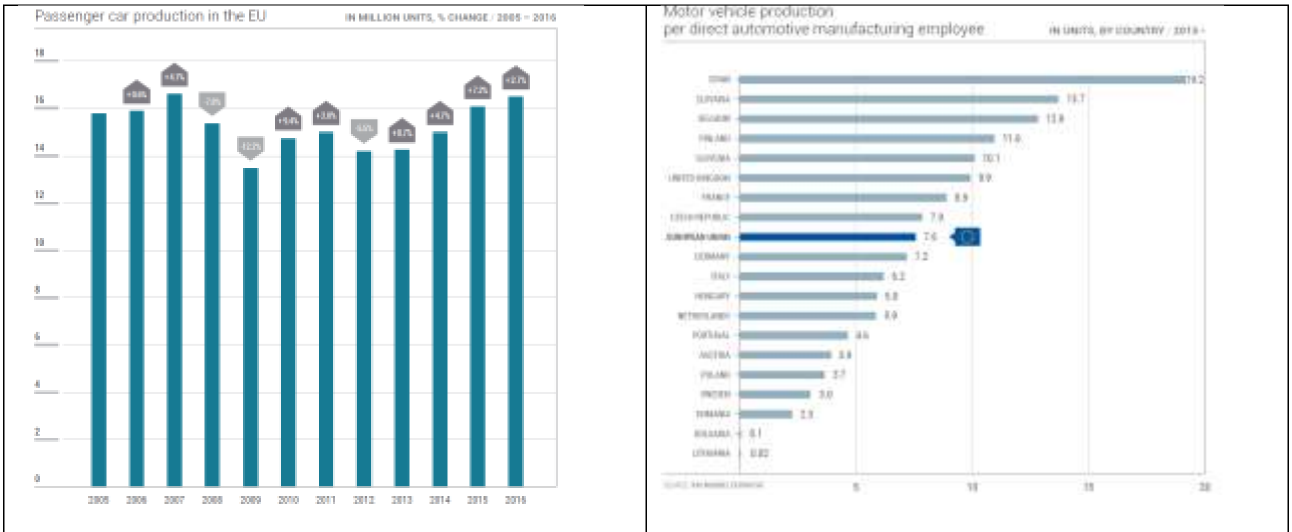


Figure 6: Pie chart of year 2016 relative to the production volume for passengers cars (86%) to heavy commercial vehicles (2.2%).



(a) (b)

Figure 7: EU production of cars divided into (a) passenger cars percentage change from 2005 to 2016, (b) motor vehicles' production per direct automotive manufacturing employee by country 8y-2015).

It is worth noticing that the graphs (graph a) represent the percentage change of car passenger EU production of year 2016 respect year 2005, and then (graph b) the motor vehicle production *per direct automotive manufacturing employee*, based on the most recent direct automotive manufacturing database available and the table I which follows, containing the direct automotive manufacturing employment by country for y-2015 assumed equal to y-2016:

Direct automotive manufacturing employment — BY COUNTRY / 2015

Austria	30,804	France	224,000	Netherlands	20,295
Belgium	30,838	Germany	850,857	Poland	178,274
Bulgaria	20,512	Greece	1,765	Portugal	33,436
Croatia	2,825	Hungary	88,532	Romania	168,689
Cyprus	104	Ireland	2,311	Slovakia	66,356
Czech Republic	159,732	Italy	159,148	Slovenia	12,746
Denmark	1,606	Latvia	1,821	Spain	142,480
Estonia	3,233	Lithuania	4,496	Sweden	68,336
Finland	7,282	Luxembourg	314	United Kingdom	169,000
		European Union	2,449,792		

Table 1: Report of the direct automotive manufacturing employment by country for y-2015 assumed equal to y-2016.

The European market seems to present several different speeds: Spain (fresh bodywork), France (in search of a higher gear), Germany (solid), Belgium (at a standstill), UK (top speed) and Italy on time to change engine(s). Italy has taken action but the main problem is the ever-decreasing supply produced by Italian automakers which have lost considerable market shares in Europe [5,10]. However among the five factories in Italy, surely underutilized, FIAT's management announced the new production plan: the slow growth of 1% vehicles production respect to the 400,000 units produced in 2014 (+3% in 2014, +4% in 2015, and +5% in 2016) preannounce a long way to get out from crisis levels and go back to the 2.5 million units produced in the pre-crisis period. In particular Alfa Romeo and Maserati brands will take time before new models will be launched. Romania, Hungary and Bulgaria (of the eastern Europe area) are today in full crisis and although these three markets are extremely small-only 1% of the European market- they are symptomatic of the intensity of the crisis from which the European automotive industry is yet to emerge.

Nonetheless, the overall of Europe is among the world's biggest producers of motor vehicles and the automotive sector represents the largest private investor in research and development (R&D). In the global transport field, the US represents the 1st producer with a low rating risk, but Germany finds in the third place with a sensitive risk rating.

Figure 8: Worldwide comparison for road transportation production and related sector risk rating (on the right side of the figure).

In the subsector of road transportation the US still remains the first largest economy in the world, followed by Europe due to the presence of UK, German, Spain, France, Belgium and Italy markets, and then by China.

China is, however the leader for the monthly registration of passengers vehicles by producers, being at 38% on the overall world contribution [10].

In the figure below it is reported the Gross Domestic Product (GDP) of year 2015 but the data have also been confirmed by 2016 statistics [11,12] .

Figure 9: Nominal GDP IMF WEO (for year 2015).

Finally it is reported an ACG statistic which compares the years 2013 (gray) and 2014 (yellow) for the main European producing Countries. The leader Countries for the automotive industry in Europe are UK and Germany followed by Spain and Belgium, as depicted in the graph reported.

Europe has the know-how, the ability and the ambition to lead the world in developing the technologies (once for all the CFRPs products) required to reach a level of annual growth as before 2009. The situation seems to be quite positive but much more has to be done.

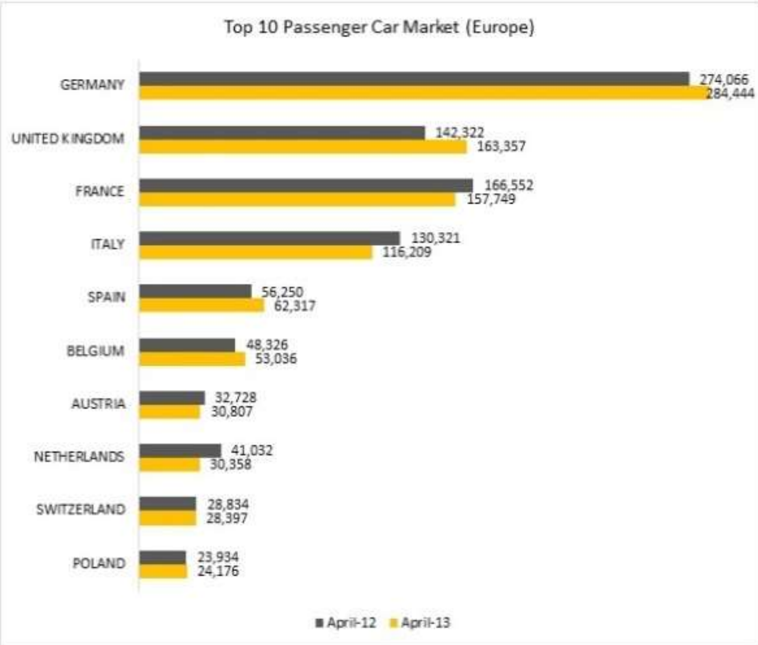


Figure 10: European top 10 passenger cars' market.

6. SWOT ANALYSIS

Hereafter it is reported the SWOT analysis. Among the **strengths** there are the improvement of cost/benefit ratio, which will be implemented in the Financial Analysis paragraph, drafted according to the well-known Discounted Cash Flow (DFC) method. Only one main **weakness** is presented and it could be related to the lack of compliance between automotive components' requirement and composite material chosen. Possible **threats** may come from low reproducibility levels and high costs of the final product respect to competitors but largely rewarded by the great **opportunities** in the automotive components as well as in other industrial sectors.

STRENGHTS	**WEAKNESSES**
– Use rCFs substituting virgin CF – Repeatable rCFs properties – Improvement of cost/benefits ratio – Higher strength/weight ratio contextual to a competitive cost and weight reduction	– Potential lack of compliance of rCF rein-forced composites properties with the requirements of the automotive components

– Wider use of CFs in automotive components, with a clear advantage in terms of automotive lightening – CO_2 reduction which is associated with a reduction of fuel consumption that can be only obtained reducing the weight of cars	
OPPORTUNITIES – Wide applicability of the products in different vehicle parts: interiors, body, chassis – Enhanced products for different industrial sectors	**THREATS** – Low reproducibility of rCFs-based composites due to different sources of CFs – Product cost not compliant with automotive market competitiveness

Table 2: Resuming SWOT analysis.

7. GO-TO-MARKET STRATEGY

The first target point to reach in this paragraph is to develop a go-to-market strategy, considering external variables, both macro-environmental (such as economic, technological, political-legislative and so on) and micro-environmental (i.e. demand and competitiveness) with the large aim to reach 85%, by weight, of the materials used in each car and light truck.

Starting from the draft Business Model of the Project Revalue and using the CANVAS scheme the go-to-market has been assessed. Besides the EU targets for 2020 (95 g CO_2/km), there are at the same time the international fuel savings targets of about 5-7% for each 10% weight loss [8]. The hard targets to reach can be assesses by a pooling action so that the average CO_2 emissions will be calculated for the pool fleet and not at the manufacture level. A pooling strategy for each manufacturer will able to decrease the level of the fines paid to the EU.

The macro-environmental variables can be summarized in the PEST analysis scheme [14] here reported where a multiple variables scenario is constructed to follow the market growth.

POLITICAL	ECONOMIC	SOCIAL	TECHNOLOGICAL
• ecological/environmental issues • future legislation • international legislation • government policies • government term and change • trading policies • home market lobbying/pressure groups • international pressure groups	• economy trends • overseas economies and trends • taxation specific to product/services • market and trade cycles • specific industry factors • market routes and distribution trends • customer/end-user drivers • interest and exchange rates	• lifestyle trends • demographics • media views • law changes affecting social factors • brand, company, technology image • consumer buying patterns • fashion and role models • major events and influences • buying access and trends • advertising and publicity	• competing technology development • research funding • dependent technologies • replacement technology/solutions • maturity of technology • manufacturing maturity and capacity • information and communications • consumer buying mechanisms/technology • technology legislation • innovation potential • technology access, licensing, patents • intellectual property issues • global communications •

Table 3: Multiple variables scenario for the market growth.

The PEST analysis is a very popular and useful tool for helping and understanding the reduction or growth of a certain market, including the different benefits and opportunities the business itself has. Let's glance to some economic, political, social and technological aspects depicted in the Pest Analysis, for our case. A choice was made among different variables. It is evident from the list reported above, that numerous technological aspects have to be fulfilled and represent the key point for the future of the automotive sector. The boundary conditions are mainly contained into the political issues. For the period 2018-2020 it has already been evidenced the difficulties and the pressures on the automotive market by the environmental targets imposed and the international agreements. Everything worsened by a competition existing in the segmented geographical European market represented by Germany, UK and France (according to ACG statistics). The chronology of EU CO_2 regulation is reported below

In 2017 a change in the exhaust emission calculations (especially for CO_2) has been approved. In fact the main differences of Worldwide Harmonized Light Vehicles Test Procedure (WLTP) calculations and the previous New European Driving Cycle (NEDC) are:

4 phases are considered instead of 2; gear points is different for each car and many technical specifications are required for gear points; a new test mass definition is considered.

Another, and second target is to reduce the gap between the present state of the art of our technological research (TRL 5) and the foreseen level TRL (9), when the products will be ready to be launched in the automotive market. The following intermediate objectives must be fulfilled:

- develop transformative technologies with reduced cycle time; the open challenge is the standard sizing procedure to restore surface coating of the fibers;
- compounding process optimization and thermoplastic compounds characterization
- validation of demonstrator by the End-user (FCA)
- OEM/Tier1 entrance for commercialization of the products and final plan for cost reductions .
- Hereafter, a simplified flow chart of the Go-to-market strategy for the REVALUE PROJECT is reported.

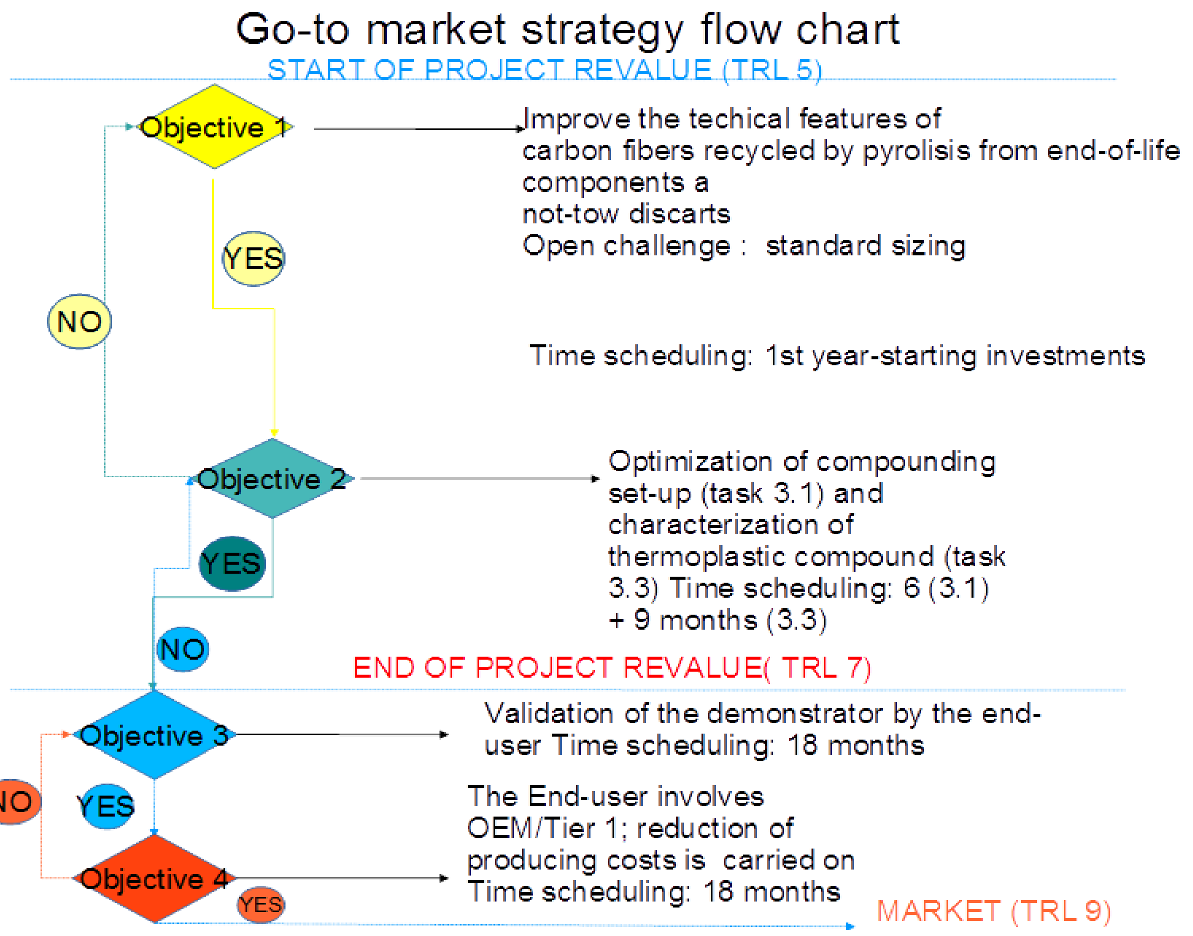


Figure 11: Flow chart of the GO-TO-MARKET strategy in the case of study of interest for the Project REVALUE.

In the objective 4 the cost reduction in composite parts can be reached increasing the volume production or decreasing the cost of the materials and of time-cycles production. The objective should be completed within the third year after the end of project. The time foreseen to reach the final aim is therefore three years after the end of Revalue Project. Apart the uncertain volumes of CF supply which is the primary reasons why CFRPs have remained confined to low production volume models, another important unknown technological variable is the reproducibility of the process which provides the regeneration of the fiber surface coatings. In other words the surface treatment which restores the mechanical properties of the composite. Once established the maturity of the processes and technologies, the future of automotive will be dominated by lightweight materials. According to Technavio's research the light commercial vehicle market in Europe will grow at a CAGR of about 3% during the period 2016-2020 against the CARG of 7% in the global automotive industry [8, 11]. The rising number of light car vehicles (LCV) in Europe has led OEMs and EU regulatory bodies to improve and enhance the safety aspects of LCVs. Numerous OEMs are providing driver training in new technologies and special seminars on safe driving to improve driving skills. Such advanced safety features are expected to drive the market for LCVs in Europe during the period 2016-2020 [13]. Light commercial vehicles are gaining popularity over heavy commercial vehicles, as the former have low operating and maintenance cost and are more fuel efficient. Also, emission and fuel norms are tougher for heavy vehicles compared to light commercial vehicles. This has led to decreased demand for heavy vehicles in Europe, and the market for these has been captured by light commercial vehicles. What volumes of production are expected? A European CFRs industry declared a 2,000 metric tons [4.4 million lb] of waste generating 1,000 metric tons of reclaimed CF per year using a patented pyrolysis process and a 21m/69-ft long belt furnace. Current estimates of combined RCF capacity run from 3,500 to 5,000 metric tons (>7.5 million to 11 million lb) per year, but with an efficiency of 50%. Taking into account that the average weight of a mass-vehicle is between 1200-200Kg and that only a percentage (maximum the 12% on the unitary mass) will be represented by RCFs it results that with 2500 metric tons about 9800 cars/year can be produced. The DOE Vehicle Technologies Program sets a goal of a 50% weight reduction in passenger-vehicle body and chassis systems. The challenge will be the structural and safety requirements for body structures, because they need additional failure mode information, materials with equal or better performance at equivalent cost, better design tools and dependable joining technology for composites, all at adequate manufacturing speeds and consistency for more common vehicle models. The potential market should also consider a fully recyclable final product as a final part of the project is devoted to the replacement of thermoplastic polymers as with PP and PA6 recycled. The commercialization will be in charge of the partner which is directly involved in the assembly of the car parts obtained in recyclable composites, obviously after the end of the Project. It is assumed that a constant degree of market penetration is assessed at 10% for the next 5 years in the European market scenario (considering mainly the English, German and French automotive industries).

8. ADVANTAGES FOR THE OEM IN REPLACING GFS WITH RCFS IN AUTOMOTIVE COMPONENT

A clear advantage in replacing GFs with RCFs in automotive components is the lightweighting, which means both reduction in fuel consumption and reaching the target of CO_2 emissions foreseen in 2020. The fulfilment of this target means also to avoid to pay expensive Government fees.

Another important issue, from the sustainability point of view, is the Circular Economy approach. One of the sustainability drivers is the discovery of high-tech solutions for the use of recycled materials that, although without a direct economic connotation, they are evaluated positively within the Dow Jones Sustainability Index.

9. FINANCIAL ANALYSIS

9.1. Financial analysis for Sizing process

The objective is to have an estimate of the main factors involved in generating profitability of the investment. This analysis will be exploded during the final business plan.

Discounted Cash Flow (DCF): The discounted cash flow is a method of evaluating an investment, based on discounting, according to a correct rate for the risk of future cash flows expected from investment.

Cash flow: is equals to sales revenue minus its cost of goods sold (gross margin). In the following the main assumptions on which the financial analysis is based, are reported:

- Time: 8 years.
- Initial investment: Capex 280,000 €;
- Opex: 1.6 M € (∑ 8 years)
- Production volume: as indicated by ELG Carbon, a production volume of between 150 and 300 tons;
- Simplified assumptions of investment: investment (Capex) is made all in year 0.
- Selling price: It depend from fixed and variable cost. Simplified assumptions of average Mark up of 30%.
- WACC: for calculating the NPV is 8.49%. It’s the WACC for chemical Basic sector.

9.1.1. Sizing manufacturing costs

A method to estimate manufacturing costs is suggested by: US department of Energy & ORNL ASME 2016 11th International Manufacturing Science and Engineering Conference.

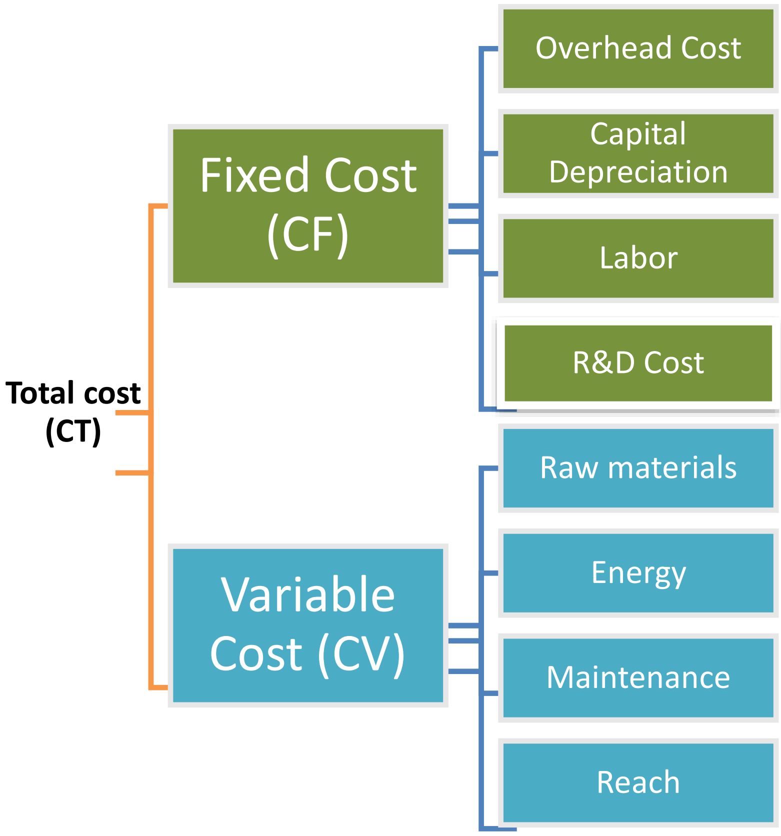


Figure 12: sizing manufacturing costs.

This cost model accounts for the fixed and variable costs involved into a sizing process of carbon fiber.

Fixed costs: Overhead cost, such as administrative and structural cost, these costs are needed in order to operate a business. Capital depreciations: is a non-monetary cost, is often viewed as a fixed cost or fixed expense. Labor is cost related to direct labor. Some companies operating in sectors, such as chemical, adopt a production process that is not infrequently integrated and automated; consequently, it seems legitimate that in such productive combinations of work resource are mainly reserved for monitoring and supervision tasks installations. Cost of labor is considered among the components fixed (semi-fixed or fixed scalar costs, it make available a certain capacity). R&D is considered a fixed cost.

Variable costs: such as Raw materials, energy, maintenance and reach are considered variable cost, they depend from the volume of production.

9.1.2. Cost estimation structure for sizing process

In the sizing process sizing agent is used. It is the contributor to the raw material cost. The treatment can increase the weight of the fiber by 0.5 to 5 percent.

According to research, the cost of the sizing process contained is indicated between € 1/1.50 to kg. It mainly depends from the volume of production, and from the ratio of the emulsion's mass per kg of carbon fiber being processed.

Estimated sizing process cost 1.00 €/kg (about 0.44 are variable costs + 0.56 Fixed costs).

Materials, labor and energy/utilities account about 67% of total cost.

The energy consumption in the sizing process is due to pre and post drying sub-processes.

Labor is estimate at 1 persons (average wage € 40k/yr), it double when volume of production will be double (it make available a certain capacity).

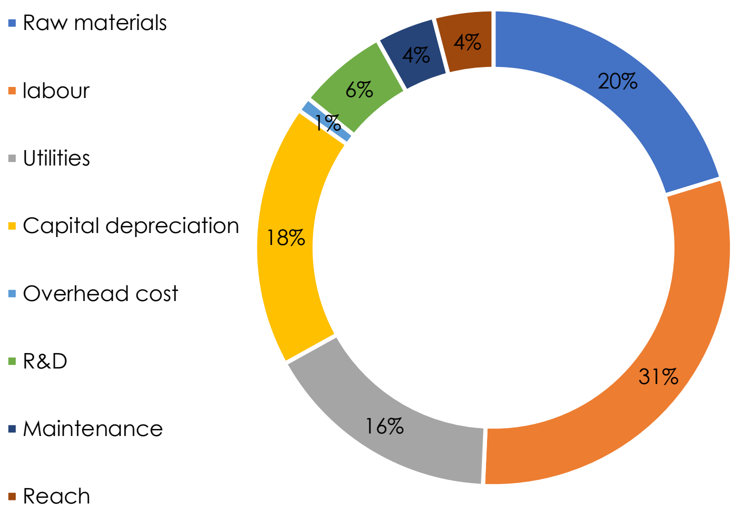


Figure 13: Apple pie of cost breakdown structure.

9.1.3. Results

The IRR is higher of the cost of capital (12%> 8.4%), so after having paid the initial investments and the production factors, the project succeeds in releasing positive cash flows of € 46.7k (Net Present value).

According to CSI Market ROI of basic materials sector: Basic Materials Sector achieved return on average invested assets of 10.13 % in 3 Q 2017, above Sector average return on investment. The return on initial investment (NPV/CAPEX) of the project is 17%, higher than an average return on investment of sector.

According to CSI Market current gross margin reach 29%. The gross margin of project is about 30%, in line with the current gross margin of sector.

Total production volume (8 years) is 1.59 Millions of kg. Break-even point (BEP) on quantity is attended near to 1M kg (It will be reach on the 5th and 6th year of production). Payback period, as it is also shown by the cumulative cash flow, is reached at the 5th year (at 5 year and 3rd month).

In a first estimate, the project looks profitable if a production volume of more than 100 tons is achieved annually, with a gross margin of at least 20%. In these terms, an additional cost of recycled carbon fiber is estimated at about 1.30 €/kg. The price indicated by the manufacturer per kg of RFC is 10.45 €. A probable price is estimated with the implementation of sizing process of approximately 11.75 €/kg, or on a ranging between 11.5 and 12 €/kg.

WEIGHTED AVERAGE COST OF CAPITAL (WACC)	8,49%
NET PRESENT VALUE (NPV)	€ 46.706
INTERNAL RATE OF RETURN (IRR	12%
BREAK EVEN POINT (Q/KG)	1.023.933
PAYBACK (Years)	5,36
RETURN ON INVESTMENT (ROI)	17%

Table 4: Sizing financial analysis indexes.

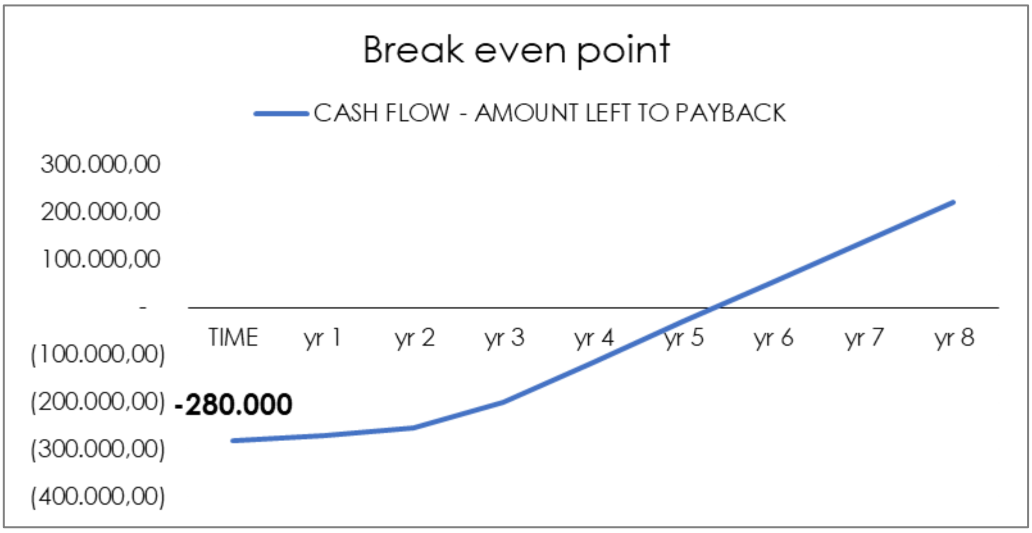


Figure 14: Break-even point for sizing financial analysis.

9.2. Financial analysis for the automotive component

The proposed technology must show a satisfactory return of initial investment, in order to justify its economic viability and commercial deployment. Therefore, starting from the previous parameters estimations, in this section the potential financial return of the proposed technology is presented, based on the method of *Discounted Cash Flow* (DCF). DCF uses future free cash flow projections and discounts them to arrive at a present value estimate, which is used to evaluate the potential for investment.

Parameters evaluated in the financial analysis are the *Net Present Value* (**NPV**), the *Return on Investment* (**ROI**), the *Internal Rate of Return* (**IRR**) and the *Discounted Payback Period* (**DPP**). The investment will be profitable if the following conditions will be satisfied:

1. NPV is positive (NPV>0),
2. IRR is higher than the applied discount rate,
3. ROI is not lower than ROI of the overall market .

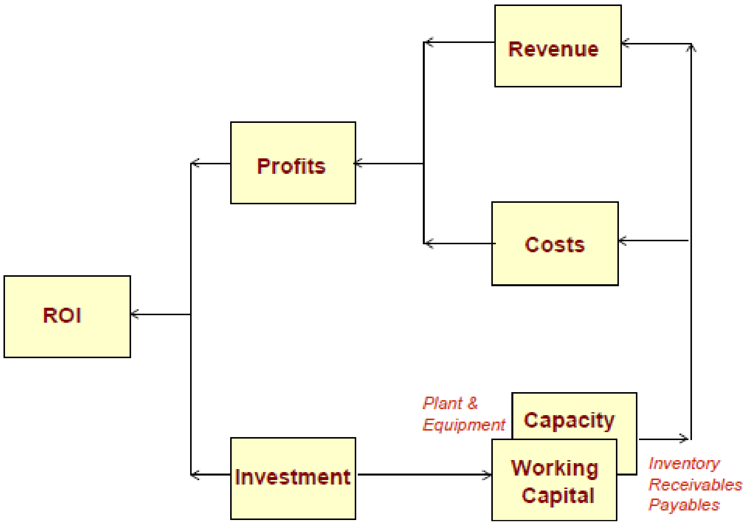


Figure 15: The ROI tree scheme followed in this financial analysis.

In figure 15 it is reported the ROI tree scheme followed in this financial analysis.
Partner interested in commercialise the proposed thermoplastic compound reinforced with high value rCFs is Fiat Chrysler Automobiles (FCA) Group, which designs, engineers, manufactures and sells vehicles and related parts and services, components and production systems worldwide.
The time to Market can be estimated in 3 years after the end of the Project (2019). In this period the innovative production and the value chain consolidation will occur, together with investments on the tooling upgrading by industrial companies involved in the process value chain. By 2023 the new solution will enter within the product development timing of a new vehicle.
Beside this base-case, two further scenarios will be considered:

- **worst-case scenario**: CRP-based components penetration of about 8% of FCA vehicles per year,
- **best-case scenario**: CRP-based components penetration of about 12% of FCA vehicles per year.

The component proposed as potential candidate for the final application, and considered for the drafting of this financial analysis, is the **front-end subsystem** (Fig. 16). It is a complex assembly unit with very high functional and aesthetic demand, protecting basic parts of the vehicle (e.g. engine cooling fan and radiator) and its occupants or pedestrians in case of collisions. Moreover, it comes in contact with the engine compartment, experiencing very high temperature, debris from road and varying weather conditions. This is why at today it is commonly made with metals (steel or aluminium) but in recent years different mixed materials including composites are widely considered as viable substitute.

Figure 16: Front-end subsystem.

Starting with one single part of proposed component per FCA vehicles, a progressive increasing of components per vehicles is expected, as in Table V. It is expected that further investments in tooling upgrading are needed when an increment in the number of the parts occurs. At least, an average price of the component thermoplastic compound reinforced with rCFs is estimated to be not less than 20 € at the market entrance with an increase of 2% per year. The price of the automotive components is estimated to increase when GFs are replaced with rCFs. On the other hand, a lightening of the final component is expected. Considering the rCFs load in the final product (about 12%), the increasing price of the component is estimated to be in the range 3,5 – 4 € for kg of lightening. This price is considered interesting for FCA that can introduce the material into its Development Area and planning the installation on its cars within 2 years .

9.2.1. Financial hypothesis

The main assumptions at the base of the financial analysis are hereafter summarized. We refer to this assumption as the “base case”.

- <u>Simplified assumption on investment</u>: all the investments are made in the first year;

- <u>Total investments</u>: 17,600,000 €;
- <u>Component price</u>: 20 €, with an annual growth rate estimated in 2% per year;
- <u>Discount rate applied</u> is the Weighted Average Cost of Capital (**WACC**) that, according to the New York University Steinhardt economics school database [15], for the Auto parts sector is 10.65%. We are supposing that it will be constant within 7 years after commercialising the product;
- <u>Cash flow</u> are estimated as earnings before interest and taxes (**EBIT**) and discounted cash flow are calculated according to the formula:

$$\sum_{i=0}^{N} \frac{EBIT_i}{(1+WACC)^i} \qquad [1]$$

where $EBIT_i$ is the profit expected in the i-th year, calculated by subtracting the investments (CAPEX) and operational costs (OPEX) from revenues.

9.2.2. Business Plan

Hereinafter, the preliminary Business Plan for the front-end system as resulted from the above mentioned assessments is reported:

Year		2023	2024	2025	2026	2027	2028	2029	2030
Revenues									
Component Price (€)		20	20,4	20,8	21,2	21,6	22,1	22,5	23,0
Parts RCFs - Based (Ku)		150.000	150.000	300.000	300.000	1.200.000	1.200.000	1.800.000	2.400.000
Parts per FCA Cars		1	1	2	2	4	4	6	8
FCA Vehicles		1	1	1	1	2	2	2	2
Total Revenues		**3.000.000**	**3.060.000**	**6.242.400**	**6.367.248**	**25.978.372**	**26.497.939**	**40.541.847**	**55.136.912**
Cost									
Capex - investments									
Opex - operational costs		800.000	800.000	1.600.000	1.700.000	7.000.000	7.300.000	11.400.000	15.800.000
Total Cost		**800.000**	**800.000**	**1.600.000**	**1.700.000**	**7.000.000**	**7.300.000**	**11.400.000**	**15.800.000**
Annual profit	-17.600.000	2.200.000	2.260.000	4.642.400	4.667.248	18.978.372	19.197.939	29.141.847	39.336.912
Discounted annual profit	-17.600.000	1.988.182	1.845.761	3.426.441	3.113.115	11.440.019	10.458.177	14.346.700	17.501.237

Table 5: Preliminary Business Plan for the proposed component.

9.2.3. Financial analysis on investment

Expected Profit and Loss (P&L) and the risk encountered by the exploiting partner (FCA) in the commercial deployment of the proposed market are below estimated. From Table V, CAPEX and OPEX for the entire investigated period are 17,600,000 € and 46,400,000 €, respectively.

Net Present Value

The NPV of the Project is calculated by subtracting the CAPEX and OPEX to the sum of the discounted expected annual revenues. The discount rate applied is the WACC assumed as above (10.65%) and supposing it will be constant within 7 years after commercialising the product.

$$NPV = \sum_{i=0}^{N} \frac{EBIT_i}{(1+WACC)^i} \qquad [2]$$

From data in Table IV it results that expected NPV in 2030 will be 64,119,663 €. This value is positive and reveals that the market introduction of the proposed product is estimated to be convenient.

Return On Investment

The ROI of the Project in the entire considered period is calculated as the difference between the NPV and the CAPEX divided by the CAPEX. In this way it provides the amount of return on an investment relative to the investment's cost.

$$ROI_{8\ years} = \frac{NPV - CAPEX}{CAPEX} \times 100 \qquad [3]$$

The annual average ROI ($\overline{ROI}$) is calculated from the following equation:

$$NPV = CAPEX(1 + \overline{ROI})^8 \qquad [4]$$

The estimated ROI in the entire period is 264%, ensuring that the cash benefits out of the project will be approximately 2.6 times as great as the original investment. In addition, the annual average ROI stands at 17.5%, therefore higher than the average ROI in the Auto & Truck parts Industry that is about 9.95% in the 2nd Quarter of 2017 [16].

Internal Rate of Return

For good management decisions, the WACC must be compared with the Internal Rate of Return (IRR) of the project. It is defined as the average discount rate where the cash benefits and costs are exactly equal, according to the following formula.

$$\sum_{i=0}^{N} \frac{EBIT_i}{(1+IRR)^i} = 0 \qquad [5]$$

IRR of the project calculated in accordance with equation (5) is 39%, greater than WACC, therefore we should consider accepting the project, resulting in a positive NPV.

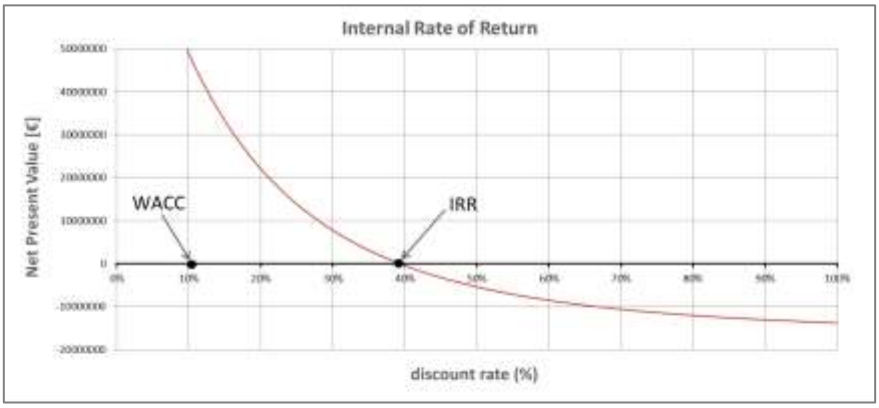


Figure 17: Internal rate of return for the proposed component.

Discounted Payback Period

In addition, the discounted payback period of the Project has been estimated, defined as the time in which the initial cash outflow of an investment is expected to be recovered from the cash inflows generated by the investment. The discounted cash inflow for each year "*i*" has been calculated as the actual cash inflow divided by the present value factor $(1+WACC)^i$.

The DPP has been calculated according to the formula:

$$DPP = i + \frac{a}{b} \qquad [6]$$

In the above formula,

"*i*" is the last year with a negative cumulative discounted profit;

"*a*" is the absolute value of cumulative discounted profit at the end of the year "i";

"*b*" is the discounted profit during the year "i+1".

According to formula (6), the DPP for the project is 4.6 years.

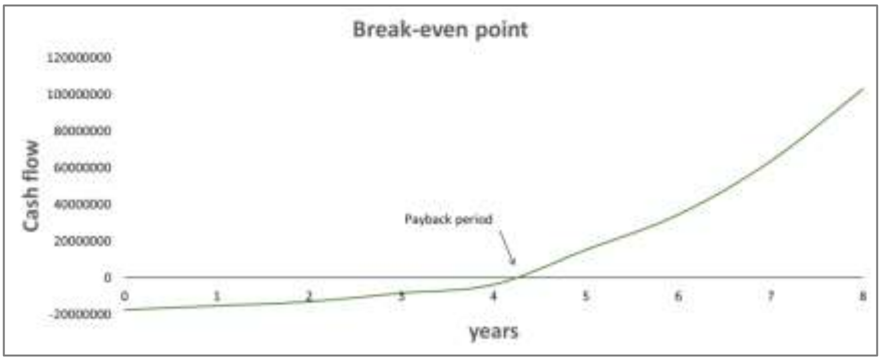


Figure 18: Break-even point for the proposed component.

9.2.4. Worst-case scenario

If a penetration of 8% of CRP-based components of FCA vehicles per year is considered, as a less optimistic scenario, financial parameters changed as following. NPV will set at 46,389,856 € therefore positive. ROI drops to 12.9%, therefore yet higher than average ROI in the Auto & Truck parts Industry. IRR decreases to 31%, but yet higher than WACC, confirming the economical convenience of the proposed product. The time required for investment returns to cover the investment cost is higher, resulting in a DPP equal to 5.2 years.

9.2.5. Best-case scenario

In case of a penetration of 12% of CRP-based components of FCA vehicles per year, both NPV, ROI and IRR increase. Beside this, the recovery of investment costs is faster.

Table 6 summarizes the financial parameters in the three different scenarios.

Scenario	Penetration market	NPV [€]	Annual ROI (%)	IRR (%)	DPP [years]
Worst-case	8%	46,389,856	12.9	31	5.2
Base-case	10%	64,119,663	17.5	39	4.6
Best-case	12%	81,849,409	21.2	46	4.3

Table 6: Financial indicators after 7 years of market entrance.

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