Sustainable Alternatives for Logistics in Aerospace

Afonso Rebelo Abelaira Lino Marques
afonsoabelairamarques@gmail.com

Instituto Superior Técnico, Universidade de Lisboa, Portugal
June 2018

Abstract

The aerospace industry is growing due to the high demand for aircraft production. The main industry players, are becoming aware of the supply chain impacts in their competitive position, and they are using composites materials to reduce components' weight, improve manufacturing times and save costs. Embraer is one of the four main OEM's and therefore it is continuously improving its processes to be competitive against the other companies. An efficient management of sustainable supply chain requires decision support tools to evaluate sustainability, with the integrated approach of the Triple Bottom Line (3BL). The present work starts by contextualizing the aerospace industry followed by the aerospace market and problem characterization. A literature review is made, focusing on relevant subjects to support the development of the evaluation of sustainable supply chains. Furthermore, the methodology used to conduct the case study research is introduced. Finally, the scenarios are defined based on the data collection followed by an economic and environmental analysis. The scenario with the best trade-off between higher profit, lower risk and lower environmental impact was S2.4 which corresponds to the Hot Stamping Thermoforming process.

Keywords: sustainability, supply chain, aerospace, aeronautics, Embraer

1. Introduction

The Aerospace and Defense (A&D) industry serves two main markets as the name indicates and has become extremely competitive. Boeing, Airbus, Bombardier, Embraer and other entrants from China and Japan, are companies of this industry that face aggressive international competition against each other (Boeing, 2016). This industry is attractive due to its growing markets which increase capable new competitors and inspire existing challengers to do better (Boeing, 2016). Global economic and geopolitical tides are changing constantly, and the customers consistently demand more value for less money (Boeing, 2016).

Since the global demand for aircraft is growing this industry is using composites to reduce weight, improve manufacturing times and save costs (Holmes, 2017). The composites industry is developing new products to meet these needs. Analysts are projecting a 33% growth in the global composite market of 43.5 million kg in the next five years for the A&D industry (Holmes, 2017).

Associated with New Product Development (NPD) is the necessity to look for new processes to manufacture the new component. Embraer is part of this industry and therefore it is continuously improving its processes to be competitive against the other companies. In this context, the motivation for this work emerges, where the sustainability of the supply chain of Embraer will be analysed by characterizing new sustainable supply chains for different alternatives, of both new processes and new materials, to produce a new component for commercial airplanes such as flaps, tails or wings.

This study is part of a larger project, Introduction of Advanced Materials Technologies (IAMAT) into new product development for the mobility industries, where the Massachusetts Institute of Technology (MIT) Portugal, This work is part of a larger project, Introduction of Advanced Materials Technologies (IAMAT) into new product development for the mobility industries, where the Massachusetts Institute of Technology (MIT) Portugal, Técnico Lisboa (Instituto Superior Técnico, IST), Faculty of Engineering of the University of Porto (Faculdade de Engenharia da Universidade do Porto, FEUP), the University of Minho (Universidade do Minho) and the Foundation for Science and Technology Portugal (Fundação para a Ciência e Tecnologia, FCT) all collaborate between them.

There are five working packages (WP) and this work is part of the fourth one, WP4 - Supply Chains Towards Sustainability. This WP intends to define the framework and tools to evaluate and quantify the supply chains impacts of product design choices for Embraer Évora. This work will evaluate the sustainability of the supply chain of Embraer Évora.chain impact in sustainability even more relevant.

2. State of the Art

Sustainability is a very broad notion and still lacks clarity, leading to a lack of success in translating the theory into practice. This is mainly due to the fact that sustainability and sustainable development concepts are not clearly standardised and defined, there is a lack of standardisation on what to measure and how to measure sustainability in supply chains, there are conflicting points of view and interests imposing trade-offs between stakeholders, there are different values, ethical and cultural backgrounds, and different core activities and impacts (Azapagic and Perdan, 2000; Carter and Rogers, 2008; Clift, 2003; Hutchins and Sutherland, 2008; Mota and Soares, 2013; Vachon and Mao, 2008).

John Elkington introduced The Triple Bottom Line (3BL) concept in 1994 (Elkington, 2004): "Triple Bottom Line accounting attempts to describe the social and environmental impact of an organization's activities, in a measurable way, to its economic performance in order to show improvement or to make evaluation more in-depth" (Elkington, 1998). In 1995 Elkington attempted to clarify the pillars' meaning by naming them in a novel way: Profit; Planet; People (Elkington, 2004).

The major difference from the past models is that all three dimensions are evaluated in an equal way so it quickly became a popular way to consider economic, environmental and social aspects in decision making (see Figure 1) (Beske, 2012). The biggest gain of the 3BL was its successful understanding and adoption by several global companies in the quest to demonstrate to their stakeholders the progresses over efficiency and sustainability in the long-term (Closs et al., 2010; Hassini et al., 2012).

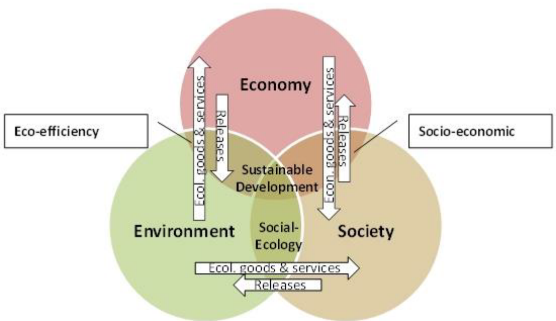

Figure 1. The Triple Bottom Line (Ruiz-Mercado et al., 2012).

"The economic dimension of sustainability concerns the organisation's impacts on the economic conditions of its stakeholders and on the economic systems at local, national, and global levels" (Global Reporting Initiative, 2011, p. 25). Edum-Fotwe and Price (2009) state that traditionally only the economic dimension of sustainability is covered. Stamford and Azapagic (2011, p. 6042) argued that "in a competitive market, financial viability is a prerequisite". Summarizing, the organisations' survival relies on the ability to manage the "economic sustainability which can be interpreted as how companies stay in business" (Doane and MacGillivray, 2001, p. 15).

"The environmental dimension of sustainability concerns an organization's impacts on living and non-living natural systems, including ecosystems, land, air, and water" (Global Reporting Initiative, 2011, p. 27). There is a growing awareness of the significant impacts of the products on the environment, therefore stakeholders and government pressures forced businesses to rethink their environmental practices across their entire supply chains (Beske, 2012; Seuring, 2012; Winkler, 2010).

"Social sustainability is a quality of societies. It signifies the nature-society relationships, mediated by work, as well as relationships within the society. Social sustainability is given, if work within a society and the related institutional arrangements:1) satisfy an extended set of human needs; 2) are shaped in a way that nature and its reproductive capabilities are preserved over a long period of time and the normative claims of social justice, human dignity and participation are fulfilled" (Littig and Griessler, 2005, p. 72). This pillar takes into account a wide variety of subjects like education, potable water, food, equity, employment, business ethics, wealth, human rights, safety, stakeholder relationship, labour standards and social responsibility (Azapagic, 2003; Closs et al., 2010; Klassen and Vereecke, 2012; Sverdrup and Svensson, 2004; Vachon and Mao, 2008; Vallance et al., 2011).

In theory the 3BL should be applicable having into consideration the three pillars and many authors have argued in favour of the equal treatment of the three dimensions in order to achieve what Sverdrup and Svensson (2004) called Integrated Sustainability (Ashby et al., 2012; Halldórsson et al., 2009; Kleine and Hauff, 2009; Spangenberg and Omann, 2006; Wittstruck and Teuteberg, 2012).

In reality the 3BL in not applicable as a whole since companies and communities face four recurring problems: 1) lack of theory such as protocols, tools, indicators; 2) metrics to assess the pillars; 3) the methodologies and guidelines are not universally accepted (Clift, 2003; Meehan et al., 2006); 4) existence of trade-offs between the pillars and the stakeholder groups add to the problem (Heemskerk et al., 2002; Kruse et al., 2008; Stonebraker et al., 2009; You et al., 2012). 1.1. Contextualisation

In the 1980's the concepts of Supply Chain (SC) and Supply Chain Management (SCM) started to emerge and they have been evolving over the past decades as the markets and consumers' requirements changed. The extended literature available on SC and SCM fails to provide a universal definition of these two concepts (Croom et al., 2000). Aitken (1998, p. 2) defines supply chain as a "network of connected and interdependent organisations mutually and co-operatively working together to control, manage and improve the flow of materials and information from suppliers to end users". Beamon (1998, p. 281) defined similarly: "A supply chain may be defined as an integrated process wherein a number of various business entities (i.e., suppliers, manufacturers, distributors, and retailers) work together in an effort to: (1) acquire raw materials; (2) convert these raw materials into specified final products; and (3) deliver these final products to retailers. This chain is traditionally characterized by a forward flow of materials and a backward flow of information." Christopher (2011, p. 3) defined SCM as the "the management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole."

A traditional supply chain is composed by two distinct business processes. One relates to the production planning and inventory control process which encompasses the inbound logistics, the manufacturing activities and the storage issues. The other one relates with the physical distribution and logistics processes, i.e., customer service and transportation activities aiming at managing the transportation services and delivery process (Beamon, 1998; Carvalho and Ramos, 2009; Min and Zhou, 2002; Tsiakis et al., 2001). A traditional supply chain may be defined as a set of companies operating individually where a forward flow of materials and products is created and a backward flow of information, orders and cash, is generated (see Figure 2) (Disney et al., 2003; Tsiakis et al., 2001; Vidal and Goetschalckx, 1997).

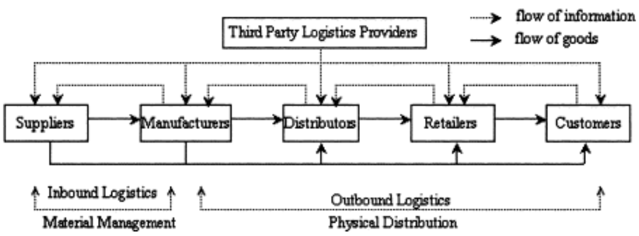

Figure 2. The Traditional Supply Chain (Min and Zhou, 2002).

The concepts of Green SC and Sustainable Supply Chain (SSC) appeared once the consumers and stakeholders started to value environmental issues and scarce resources. As a consequence, they started to pressure governments and companies to modify their operations (Seuring and Müller, 2008; Srivastava, 2007; Wu and Dunn, 1995). Green SCM is defined by Srivastava (2007, p. 54,55) as "integrating environmental thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life".

Green SCM is a concerted strategy in the whole supply chain with the following common processes: 1) "Green design": product design and conception; 2) "Green sourcing" and "Green purchasing": better sourcing strategies and policies; 4) "Green manufacturing": production and transformation stage; "Green marketing": service level and channel decisions and 4) "Green logistics": transportation, handling; warehousing, waste management, among others (Ageron et al., 2012; Barbosa-Póvoa, 2009; Srivastava, 2007; Wu and Dunn, 1995).

Meeting economic and environmental stakeholder expectations were sine qua non, i.e., necessary but not sufficient to achieve sustainability in supply chains. Therefore a new concept named Sustainable Supply Chain Management (SSCM) appeared. The difference between Green SCM and SSCM is that SSCM includes Green SCM and it is a more general concept that embraces all three pillars from the 3BL.

Seuring and Müller (2008, p. 1700) defined SSCM as "the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements". Wittstruck and Teuteberg (2012) afirmed that SSCM relied on the adoption and extension of the SCM principles and foundations. Therefore it can be seen as a materialisation of sustainability philosophy and of the 3BL into SCs (Barbosa-Póvoa, 2009; Halldórsson et al., 2009; Pagell and Wu, 2009; Teuteberg and Wittstruck, 2010).

Despite the fact that Pagell and Wu (2009) stated that no truly sustainable supply chain exists, SSCM issues have been increasingly studied alongside with its implications (Ageron et al., 2012; Seuring and Müller, 2008; Winkler, 2010). As a matter of fact, for the past two decades researchers attempted to define and implement sustainability in supply chains fighting to integrate the basic concepts from the three sustainability systems (Ageron et al., 2012; Hassini et al., 2012; Seuring and Müller, 2008).

It is important to retain that from the literature there is not a single path to implement SSCM since in theory all SC activities from purchasing to end-customer delivery are susceptible to change in order to incorporate sustainability. Also Seuring and Müller (2008) in a Delphi study found win-win situations between the three pillars to be more likely to occur than trade-offs, therefore the organisations should explore the best strategies to implement sustainability.

2. Methodology

This chapter presents the methodology used for this work. The case study methodology employs the following steps.

The research framework, constructs and questions

The scope of this study involves the analysis of the direct material suppliers to one factory that assemblies the parts in the final aircraft. The main questions to be answered were:

- What parts are currently being produced in composites and how?
- Why are they producing the parts with a specific technology?
- Are there other technologies that could be used to produce composite parts to improve the supply chain sustainability?

The variables relevant for this work and to answer these questions were defined as the costs, the time, the materials, the technologies and the means of transportation.

Choosing cases

This work is part of Embraer's project to grow and improve and once they are one of the four main players the case study chosen is about their company. The focus will be Embraer Évora, since they cooperate directly with IAMAT.

Developing research instruments and protocols

To obtain the data, emails, meetings, video conferences, phone calls are the most suitable way for this case study, with IAMAT's members, Embraer Évora engineers and Embraer Évora's material suppliers

Conducting the field research

When conducting the field research, many emails and meetings occurred.

3. Scenarios Definition and Data Collection

Nowadays, in the OEM, Embraer Évora, they produce tails of executive airplanes in composites. However, they want to start producing components for commercial airplanes such as flaps, tails or wings. The scheme of the supply chain of Embraer Évora considering that final component is targeted for executive airplanes is represented in Figure 3. Figure 4 it represents the case where the components are going to be incorporated in commercial airplanes.

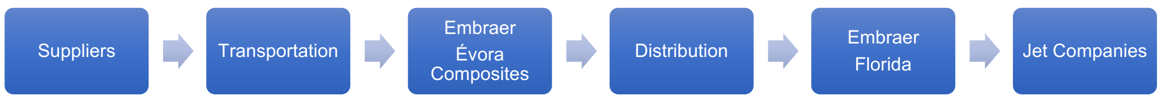

Figure 3. Supply Chain Embraer Évora Executive Aviation.

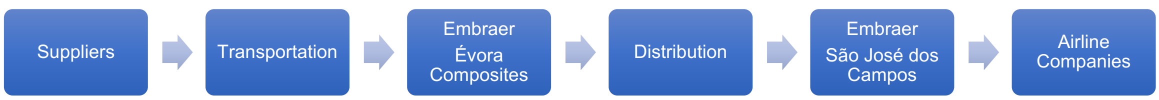

Figure 4. Supply Chain Embraer Évora Commercial Aviation.

For the different manufacture processes, IAMAT is developing a demonstrator in composites, called test-bed, which is basically a plate with stringers integrated. This demonstrator is considered a fraction of bigger aerodynamic surfaces like flaps, tails or wings. Figure 5 is a model of this test-bed demonstrator.

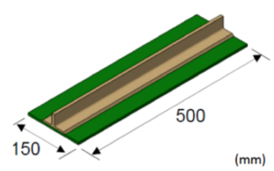

Figure 5. Test-bed demonstrator.

The following Table 1 contains the dimensions of the test-bed. To simplify the test-bed thickness will be considered as the plate thickness of the test-bed. The height of the stringer will be considered negligible.

Table 1. Test-bed dimensions.

Width (mm)	Length (mm)	Thickness (mm)
150	500	4

From a strategic point of view, the conceptual purpose of the test-bed is to manufacture composite wings for commercial regional airplanes, since they are the most interesting aero structure to consider. Since the goal of this work is to compare the sustainability of the supply chain of Embraer Évora of the different scenarios, to simplify, a reference panel with dimensions defined between a tail and wing panel dimensions of a commercial airplane will be considered. The reference panel can be seen as the junction of multiple test-beds, and the dimensions were defined accordingly with an email exchanged with one of Embraer's engineers, Ricardo Reis, and can be seen in Table 2. Again, the reference panel thickness will be considered as the plate thickness of the test-bed.

This reference panel represents a normalized perspective to compare the different possible supply chains. Therefore, all the scenarios have a similar basis of comparison. This reference panel represents a more realistic approach to analyse the different supply chains due to the fact that the dimensions are of the same order of magnitude of wings or tail panels of real aircrafts.

Table 2. Reference panel dimensions.

Width (m)	Length (m)	Thickness (mm)
5	18	4

There are four different manufacture processes: Pre-preg Autoclave Technology, Vacuum Assisted Resin Infusion (VARI), Vacuum Bag Only (VBO), Hot Stamping Thermoforming. The scenarios will now be defined. The difference of the primary scenarios is the aviation sector that the component is destined to. The difference of the secondary scenarios is the technology used for each process. The following Table 3 generally characterizes the different scenarios considered in this study.

Table 3. Scenarios' Characterization.

Primary Scenario	Secondary Scenario	Sector	Process
S1	S1.1	Executive	Pre-preg Autoclave Technology
S2	S2.1	Commercial	Pre-preg Autoclave Technology
	S2.2	Commercial	VARI
	S2.3	Commercial	VBO
	S2.4	Commercial	Hot Stamping Thermoforming

The Pre-preg Autoclave Technology is presented as the current scenario at Embraer Évora, and is considered the most common technique in the aerospace industry to manufacture high precision and performance components.

Some of the information required to analyse the supply chain of Embraer Évora could not be obtained because it is considered confidential information of the company, therefore assumptions had to be made to complete the data missing.

The different phases of the supply chain where data was collected for this work were: suppliers, transportation, production, distribution, assembly factories.

There are two suppliers of the composites materials, Hexcel and Solvay. The quantity and cost of material needed to manufacture a reference panel were calculated.

The materials need to be transported from the suppliers to Embraer Évora. Some of the materials, due to their properties, need to be transported with controlled temperature. The lead times and the transport costs for each material were also obtained.

When the materials arrive from the suppliers to Embraer Évora, the production processes start until the final product is complete. Due to the fact that Embraer is not developing the alternative scenarios proposed in this work, the data related to the processes used for each scenario were scaled from experimental laboratory tests for the production of one test-bed. Research was made in scaling up laboratory to industry results but relevant information for aerospace composites industry could not be found.

It was used a linear scale-up for the reference panel knowing the Autoclave investment, power and cure cycle at Embraer Évora.

Three tertiary scenarios were added to each secondary scenario. In the first tertiary scenario, the time ratio is used for both the operator and the machine, so it considers 1 operator for the whole process. In the second tertiary scenario, the time ratio is used for both the operator and the machine, but it considers that 2 operators are necessary for the same duration as in the first one. Finally, in the third tertiary scenario, the time ratio is used for both the operator and the machine and it considers 1 operator to control the line. The difference here is that the duration of the tasks done by the operator will be fractioned to 30% manual labour and 70% automation. The reason for this is that part of the manual labour that is required in laboratory is replaced by machines in an industrial environment.

Table 4. Operational cost of one reference panel after arriving at the centre for each scenario.

Primary Scenario	Secondary Scenario	Tertiary Scenario	Total Cost (USD)
S1	S1.1	S1.1.1	235745.6
		S1.1.2	235956.3
		S1.1.3	247721.1
S2	S2.1	S2.1.1	235825.6
		S2.1.2	236036.3
		S2.1.3	247801.1
	S2.2	S2.2.1	264039.2
		S2.2.2	264395.0
		S2.2.3	284266.7
	S2.3	S2.3.1	251021.4
		S2.3.2	251258.6
		S2.3.3	264506.4
	S2.4	S2.4.1	172984.3
		S2.4.2	173766.6
		S2.4.3	217464.6

The internal cost for the production of the reference panel and the sales price for each different scenario were also calculated.

After the component is produced, it needs to be distributed. The travelled distances and times for each scenario were obtained.

Once the component is distributed it arrives at the centre where it will be integrated in the final aircraft. The operational cost for each scenario was obtained and can be seen in Table 4.

4. Scenarios Evaluation

For this part, a business project investment evaluation was made. It was necessary to obtain the Net Present Value (NPV), the Payback Period and the Internal Rate of Return (IRR) for each scenario.

The following Figures 6, 7 and 8 compare the NPV's, Payback Period and the IRR's of all the scenarios. To simplify, the comparison will be made by scenarios category: first, second and third. The first category corresponds to all scenarios under S.x.x.1 (which means S1.1.1, S2.1.1, S2.2.1, S2.3.1, S2.4.1), the second category to all S.x.x.2 (S1.1.2, S2.1.2, S2.2.2, S2.3.2, S2.4.2) and the third category to all S.x.x.3 (S1.1.3, S2.1.3, S2.2.3, S2.3.3, S2.4.3). It is important to note that S1.1 and S2.1 are almost the same, except the aviation sector they serve. The assembly factory location is the only difference contemplated in this work, therefore the differences of the results for these scenarios are minimum.

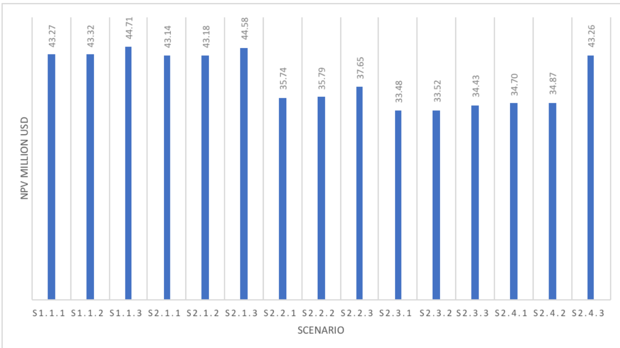

Figure 6. NPV in Million USD for all the scenarios.

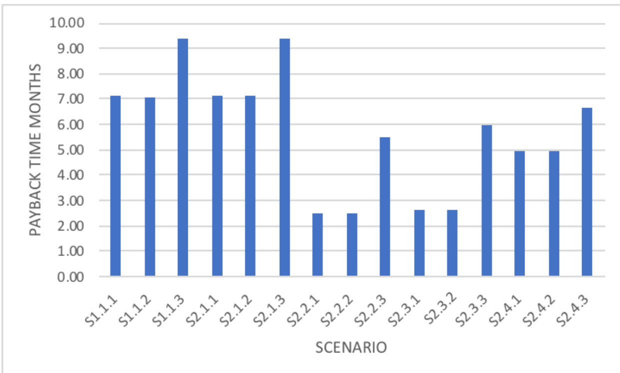

Figure 7. Payback Period in months for all the scenarios.

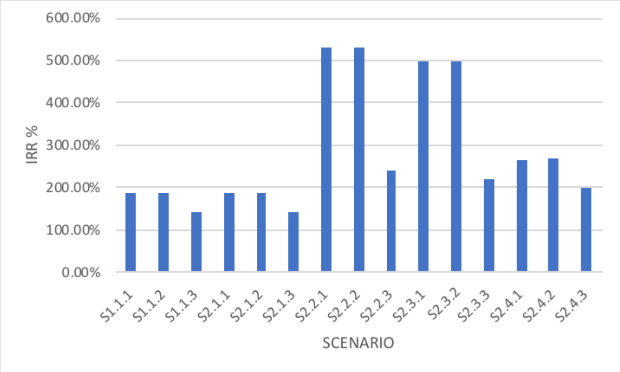

Figure 8. IRR in percentage for all the scenarios.

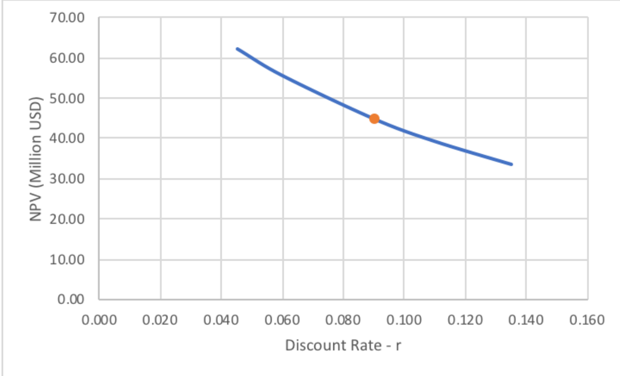

Figure 9. NPV versus Discount Rate for S1.1.3.

For all the scenarios, the NPV is bigger than zero which means that the project is profitable, since the present value with the discount rate of the liquid cash flows is superior to the investment made at the beginning of the project.

The Payback Time is not a good indicator to measure a project's profitability since it ignores what happens from the moment the investment is recovered. It is however an interesting risk measure since it allows to measure the time it takes for a project to recover the initial investment. The higher the time is, the bigger the risk is. However, all the scenarios present Payback Time inferior to one year which means they are all viable.

For all the scenarios, IRR is bigger than the discount rate, which means that the project is profitable. Higher IRR corresponds to bigger return.

All the scenarios were presented as profitable, the payback time was considered less than a year which is a really good indicator in this sector and the IRR's are all bigger than 100% which means the project is always approved.

The scenarios with more relevance to study are the third category since they correspond to the scenarios with more automation and less manual labor. A sensitivity analysis was made for the discount rate, increasing and decreasing 50% of the considered value. There is an uncertainty associated with these parameter, and the purpose is to observe how the NPV varies with this change. Figure 9 is for S1.1.3 but for all the third category scenarios the NPV follows an inverse proportion with the discount rate. When the discount rate increases, the NPV is lower but it is always positive, meaning the project is always profitable.

For the environmental evaluation, a Life Cycle Assessment (LCA) was made using *SimaPro* 8.3.0.0, and the databases Method and Ecoinvent3-consequential-unit, which is the most recent. The LCA followed the steps described in Standard ISO 14040: definition of the goal and scope, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA), and life cycle interpretation phase.

In order to have comparable values for all the scenarios, and since there are different environmental categories for each scenario, it was used ReCiPe Endpoint (H) in SimaPro to obtain a single score for each scenario, meaning that each value of the respective environmental category was normalized and added to obtain the final result. The single score results for each scenario can be seen in the following Figure 10.

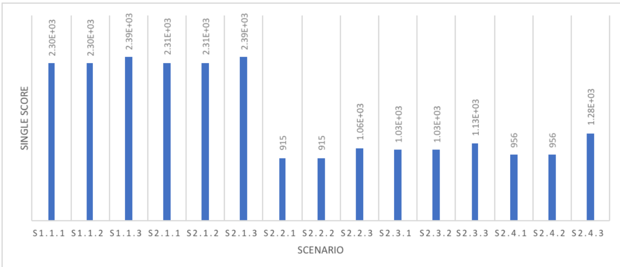

Figure 10. Single Score for all the scenarios.

The scenarios with more relevance to study are the third category since they correspond to the scenarios with more automation and less manual labor. For these it was used the Pareto's Principle, to determine the categories that contribute with approximately 80% of the total environmental impact for each scenario.

It is important to note that the categories with more impact are for all the scenarios are: climate change human health, fossil depletion, and climate change ecosystems. Climate change human health and ecosystems is related to emissions of greenhouse gases to air and fossil depletion is related to extraction of minerals and fossil fuels due to inputs in the system.

Table 5. Pareto´s analysis with the relative weight of the categories with more impact for all the scenarios.

Impact Category	S1.1.3 %	S2.1.3 %	S2.2.3 %	S2.3.3 %	S2.4.3 %
Climate change Human Health	32.02	32.00	30.80	31.19	28.57
Fossil depletion	30.61	30.61	31.00	30.41	28.52
Climate Change Ecosystems	20.26	20.25	19.48	19.24	18.08
Total	82.89	82.87	81.27	80.84	75.17

The summarized qualitative results by scenario, can be seen in the following Table 6. The scores are organized in a descendant order per row. These results are valid for the third category scenarios, which are the scenarios used as a basis of comparison, due to the fact that they are the ones with more automation, and therefore closer to reality.

Table 6. Third scenarios category economic and environmental qualitative results organized in order from the most relevant to the least relevant.

Higher Profit	Lower Risk	Lower Environmental Impact
S1.1	S2.2	S2.2
S2.1	S2.3	S2.3
S2.4	S2.4	S2.4
S2.2	S1.1	S1.1
S2.3	S2.1	S2.1

The scenarios S1.1 and S2.1 are very similar except the distribution part. S1.1 and S2.1 are the scenarios with the second highest number of number of parts produced per year but with the highest and second highest NPV value respectively. The scenario S2.4 has the highest number of parts produced per year but is third ranked on the NPV. This discrepancy is due to the fact that the sales of S1.1 and S2.1 have the highest value of all the scenarios since a fixed profit percentage was assumed for the internal cost.

The Payback Time and IRR and measure the risk and follows approximately the inverse order of the NPV. However, all the scenarios present Payback Time inferior to one year which means they are all viable and all the scenarios, have an IRR bigger than the discount rate, which means that the project is profitable.

As to the environmental results, they are referent to the production of only one reference panel, which is different from the economic results since they considered the maximum efficiency of the factory to produce parts. In this case, the highest the single score is, the more environmental impact the scenario has. The most environmental friendly scenario is S2.2 and the less environmentally friendly scenarios are S1.1 and S2.1 with quite similar single scores, being the difference again the distribution.

The scenario with the best trade-off between higher profit, lower risk and lower environmental impact is scenario S2.4.

5. Conclusions

The third category scenarios were the ones used as a basis of comparison to evaluate all the scenarios, economically and environmentally, since they were the ones with more automation and less manual labor, which is closest to the real industry. There were discrepancies in the NPV ranking and in the number of parts produced per year due to the fact that the sales were considered using the internal cost plus a fixed profit percentage. As to the single score, these results were referent to the production of only one reference panel, which is different from the economic results since they considered the maximum efficiency of the factory to produce parts. The scenario with the best trade-off between higher profit, lower risk and lower environmental impact is scenario S2.4.

As future work, it is recommended to do a different scale-up, less linear, more complex and with more variables. This scale-up was the best option for a first approach with the resources and time available, but each process is very complex and requires a more detailed examination. There are many new processes and machinery that weren't included in this work. It is not linear to scale-up a process that is done in laboratory to industry. In laboratory there is a lot of manual labor involved which is not true for industry. The learning curve for industry should also be studied with more detail, and in this work, it was reference to justify the increase of the sales per year without acquiring new machinery. It is also important to note, that if a certain manufacture process is chosen by Embraer, it is possible to acquire more machinery to increase the production of parts per year to satisfy the demand. It was considered in this work, that the machines were working at full power. It is interesting to obtain in the future, the results for the exact power of each machine, for each stage of the process.

Finally I would recommend to integrate the social pillar, which due to time limitation was not considered, to have a more complete characterization of the sustainability of the supply chain.

5.References

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