sustainability

MDPI

Article

Sustainable Business Models–Canvas for Sustainability, Evaluation Method, and Their Application to Additive Manufacturing in Aircraft Maintenance

Gonçalo Cardeal [1,*], Kristina Höse [2], Inês Ribeiro [1,*] and Uwe Götze [2]

[1] IDMEC, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal
[2] Faculty of Economics and Business Administration, Chemnitz University of Technology, 09111 Chemnitz, Germany; kristina.hoese@wirtschaft.tu-chemnitz.de (K.H.); uwe.goetze@wirtschaft.tu-chemnitz.de (U.G.)
* Correspondence: goncalo.cardeal@tecnico.ulisboa.pt (G.C.); ines.ribeiro@tecnico.ulisboa.pt (I.R.)

Received: 13 October 2020; Accepted: 30 October 2020; Published: 3 November 2020

Abstract: The topic of sustainable business models is growing in literature and in the industry, driving companies to search for opportunities to improve their impact on the three pillars of sustainability—profit, people, and planet (economic, social, and environmental). However, the process of developing sustainable business models is often complex, due to conflicting objectives from the three dimensions of sustainability. This paper presents a procedure model that supports the design and assessment of business models with a sustainable perspective, by integrating a new business model canvas for sustainability (BMCS) and an evaluation method to assess it. A comprehensive assessment is proposed, performed in a life cycle perspective. The proposed model is applied and validated with a real case study, based on a new business model for an aircraft maintenance, repair, and overhaul company. The case is based on shifting from traditional maintenance, repair, and overhaul activities to adopting additive manufacturing as an activity that allows manufacturing optimized spare parts with benefits for the costumer. The results show the application of the procedure model on a specific case study, as well as the potential of additive manufacturing as a driver for more sustainable business models in the aircraft maintenance sector.

Keywords: business model canvas; sustainability; life cycle; sustainable business model; additive manufacturing; LCA

1. Introduction

The definition of a business model appears to vary between authors; however, while there is not a definitive definition, most agree that it intends to describe how a business works and how value is created and captured [1]. Traditionally, business models focus on value creation through economic benefits, often disregarding environmental and social concerns. However, the concept of sustainability, that includes all the three pillars (social, environmental, and economic), within business model innovation, has been growing in popularity and is currently a major focus in the academic literature [2]. Geissdoerfer et al. (2018) studied several definitions used in academic literature and proposed the following definition for sustainable business models: "Business models that incorporate pro-active multi-stakeholder management, the creation of monetary and non-monetary value for a broad range of stakeholders, and hold a long-term perspective" [3] (pp. 403–404).

Often, new business model developments stem from emerging technologies and innovations, as they force actors within an industry to change the way they operate [4,5]. The changes caused by these technologies across different industries are the focus of several authors regarding potential impacts in the three pillars of sustainability [6,7]. Additive manufacturing (AM) technologies are an example of this, as they are often cited as having high potential to disrupt the structure and businesses' operations [8–10]. A change in a business model often effects the social, environmental, and economic performance of the company. However, few studies exist to support the development of sustainable business models [2,11,12]. One of the most popular tools among entrepreneurs to conceive and design business models is Osterwalder and Pigneur's Business Model Canvas [13]. However, this framework fails to map the environmental and social aspects of a business model. Although some authors have looked into integrating environmental and social aspects into the Business Model Canvas [14–16], the topic is relatively new and there is no established method for mapping and designing sustainable business models. An additional aspect to be taken into consideration when developing a business model is its assessment. Traditionally, this is assessed through financial projections that enable an entrepreneur or investor to assess the expected return. However, when expanding the sustainability scope, it is necessary to support this analysis with long term economic, environmental, and social assessment methodologies.

This paper addresses the shortcomings in sustainable business models literature with a twofold contribution. The first contribution is the introduction of a new method to conceive, design, and map sustainable business models, the Business Model Canvas for Sustainability (BMCS), focused on integrating the three pillars of sustainability in one business model canvas. Furthermore, the authors propose a procedure model to pre-select business model alternatives and assess their long-term sustainability using the BMCS. Besides these theoretical contributions, the case of introducing additive manufacturing technologies in an aircraft maintenance company is analyzed, applying the proposed canvas and procedure model. For that, the changes in the company's business model are mapped in the BMCS, taking into account the introduction of additive manufacturing. Based on this mapping, the economic, environmental, and social dimension are evaluated using the sustainability assessment methodologies suggested in the procedure model.

2. Business Model Canvas for Sustainability

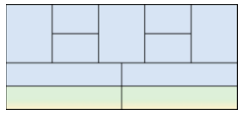
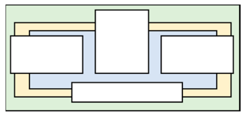
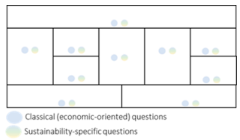
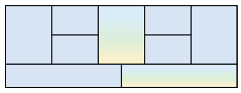
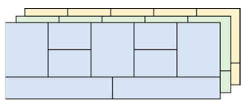
Several approaches have been developed to conceptualize business models, doing so by dividing them into different elements [13,17]. Bearing in mind that a business model is understood as the logic of creating value and the way of providing it to customers [18], the structure of the elements is economic-oriented. Osterwalder and Pigneur (2010), for example, propose the following elements: key partners, costs structure, key resources, key activities, value proposition, customer relationship, channels, customer segments, and revenue streams [13]. The resulting Osterwalder and Pigneur (2010) business model canvas is a comprehensive approach on how to analyze or develop a business model. While other models focus on different areas, namely technology, organization, or strategy [19], the business model canvas is a framework that illustrates the way a company makes business in nine structured elements. It is a very popular tool amongst entrepreneurs for its sense-making aspect of showing how a business model works [20]. However, the main focus of frameworks like the one of Osterwalder and Pigneur (2010) is economic, as shown, e.g., by the bottom aspects (cost structure and revenue stream), disregarding sustainability aspects beyond the economic dimension. Thus, it is essential to include new aspects within the frameworks to enable a sustainability-oriented business model analysis and development.

Schoormann et al. [21] identified the following possibilities on how to adapt existing frameworks by integrating sustainability aspects: modification of the element-content, division of elements, re-structuring the whole framework, addition of new elements, linking of elements, and addition of views/principles on the framework [21]. Regarding the business model canvas, several approaches of inclusion of sustainability aspects exist. Osterwalder and Pigneur (2010) propose to add two elements (ecological and social costs and revenues) [13]. Jones and Upward (2014) expand the original nine canvas elements by building four perspectives (stakeholder, product/learning/development, process, measurement) as well as new elements (e.g., biophysical stocks, ecosystem services). [15]. Fichter and Tiemann (2015) add another three new elements—business model vision/mission, competitors, and relevant stakeholders, while also proposing a Sustainable Business Canvas. At the same time, they combine customer segments, channels, and customer relationship into one single element: "customers" [14]. Foxon et al. (2015) developed a business model canvas which included sustainability for low carbon infrastructures—the nine original elements were kept the same but some of them were sub-divided into terms of sustainability [16]. Another suggestion is presented by Joyce and Paquin (2016), who expand the business model canvas by two additional layers, the environmental and the social layer, proposing the assessment of a business model under the three pillars of sustainability [11]. This framework is called triple layer business model canvas and aims to maintain the sense-making flow of how a business works, as introduced in the original canvas, represented as the horizontal coherence within the economic, environmental, and social layer. The second aim is to enable the vertical coherence between the elements of the three layers of the business model. The three layers are characterized as follows. The economic canvas is kept the same as the one proposed by Osterwalder and Pigneur [13]. The environmental layer is based on a life cycle perspective to map the environmental impact (e.g., CO_2-emissions) of a product/service over its whole life cycle. The social layer focuses on a stakeholder perspective and results from the stakeholder's management approach. [11]. Table 1 gives an overview about the presented sustainability-oriented frameworks.

All presented variations of the business model canvas include helpful ideas to integrate sustainability-aspects in this framework while developing and analyzing business models. However, some of the approaches (e.g., Osterwalder and Pigneur (2010), Foxon et al. (2015)) merely consider some of the elements of the canvas in a sustainability-oriented way (e.g., value proposition by Foxon et al. (2015)). Jones and Upward (2014) analyze all the elements in a social, environmental, and financial context [15], but as they have enhanced the business model canvas with various new elements (e.g., needs, assets), the resulting framework is very complex, reducing its applicability. Fichter and Tiemann (2015) propose to ask "classic" economic as well as sustainability-specific questions regarding the elements of their business model canvas [14]. This framework principally enables sustainability-oriented development and analysis of business models; however, there is no clear procedure for selecting which questions to ask. The framework of Joyce and Paquin (2016) is a well-elaborated approach, refined in cooperation with different manufacturers, and further developed by performing workshops with more than 400 participants [11]. However, challenges appear when trying to find the vertical coherence between the economic, social, and environmental elements within the layers. Additionally, the distinction between the three layers with differing elements indicates the existence of independent layer-specific decisions; however, in business applications, each design decision about an element or sub-element of a business model (e.g., an activity or a resource) is only made once. Often, a lot of these decisions will influence more than one dimension of sustainability, and so should be made considering the effects on all concerned dimensions.

As a conclusion, the authors of this paper propose a differing extension of the business model canvas including sustainability aspects: a canvas integrating the three pillars of sustainability without distinguishing between three different layers or introducing completely new elements. Called business model canvas for sustainability (BMCS), it comprises all nine elements of the original canvas, which are viewed as being tripartite—including all dimensions of sustainability. This approach aims to avoid the challenges of vertical coherence, resulting in different focusses (stakeholder vs. life cycle vs. customer perspective). Additionally, the integration of the three sustainability dimensions in one canvas requires the consideration of all of them in the analysis and design decisions of each of the nine canvas elements. Furthermore, all dimensions of sustainability can be looked at from a life cycle perspective. Finally, this canvas concept seems to be more systematic than the extension by single elements and less complex than the triple-layer approach.

Table 1. Overview of sustainability-oriented Business Model Canvas Frameworks. For an overview of design principles see Schoormann et al. (2016) [21]. Key: blue color—economic focus, green color—environmental focus, yellow color—social focus.

Sustainable Business Model Canvas Framework	Design Principles	Characteristics	Model
Extended model of Osterwalder and Pigneur (2011) [13]	Addition of new elements	New blocks for social/ecological costs and revenues	
Strongly Sustainable Business Model Canvas of Jones and Upward (2014) [15]	Addition of new elements, modification of existing elements, re-structuring of the whole framework	New perspectives (in white: stakeholder, product/learning/development, process, measurement) including new elements (bio-physical stocks, eco-system services, partnerships, decisions, stakeholders, actors, needs, success, assets, valuation method, tri-profit) → considered in economic, social, and environmental context	
Sustainable Business Canvas of Fichter and Timann (2015) [14]	Addition of new elements, modifcation of existing elements	New elements (business model vision/mission, competitors, relevant stakeholders), elements customer segments, channels, and customer relationship combined to one element “customers”	
BMC approach extended for infrastructure by Foxon et al. (2015) [16]	Division/addition of elements	Division of value proposition (direct consumption, social, economic, ecological) and revenue is changed to value stream and divided (fiscal, social, development, ecological)	
Triple layer business model canvas of Joyce and Paquin (2016) [11]	Addition of new layers (new Canvases), modification of the structure and content of some elements	New layers for social and environmental pillars of sustainability, elements of social layer: local communities, governance, employees, social value, societal culture, scale of outreach, end-user, social impacts, social benefits, elements of environmental layer: supplies and outsourcing, production, materials, functional value, end-of-life, distribution, use phase, environmental impacts, environmental benefits	

The suggested BMCS is composed by an adaptation of the nine elements proposed by the Osterwalder and Pigneur (2010) canvas [13]. As already mentioned, each element is extended by ecological and sociological aspects, so as to achieve a sustainability perspective too. For the sake of clarity, the dimension-specific aspects of each element are mapped in different colors (Figure 1).

The BMCS builds on a life cycle perspective centered in the value proposition of a product or service, in which the input stakeholders and activities required for the delivery of the product/service are mapped in the left. The output stakeholders, from the client to the end-of-life actors, as well as output-related activities, are mapped in the right (Figure 1). This supports users to perform a life cycle analysis on the three pillars of sustainability while mapping each element of the canvas. Thus, the BMCS maintains the point of the original Osterwalder and Pigneur (2010) canvas [13], the "sense-making," still centered on the value of a product, process or organizational innovation, while incorporating the three pillars of sustainability.

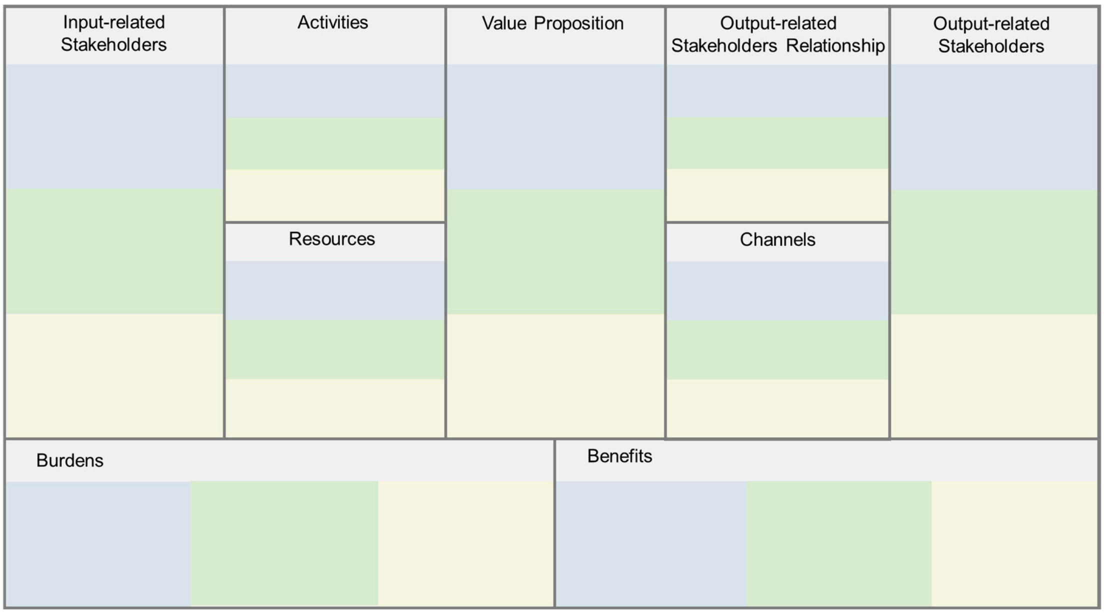


Figure 1. Business model canvas for sustainability (blue—economic aspects; green—environmental aspects; yellow—social aspects). Based on: Osterwalder and Pigneur, 2010 [13].

The *value proposition* element is an extension of the traditional business model canvas. The value proposition should describe the value of a product/service, regarding its economic, environmental, and social aspects. While the economic value is usually focused on the customer, the social value portrays the focus of the organization on having a positive impact on society in general (as e.g., within the social value perspective of Joyce and Paquin 2016 [11]), and more specifically on its stakeholders. The environmental value should focus on the added value to the planet, regarding the main environmental categories reflected in Life Cycle Assessment (LCA)—human health, resources, and ecosystems quality [22].

The input related stakeholders' element describes the partners directly involved in the upstream phases of the company's core activity. As defined by Joyce and Paquin [11], in the triple layered business model canvas, both the partners and the supply/outsourcing element comprehend that, while value chain activities are necessary, they are not considered core to the organization. A few examples of integrating the environmental dimension of the business model include water or energy consumed within the company (generally supplied by partners). The social dimension is dominated by relationships with stakeholders and local communities, namely, changes in local employment and other community-related aspects.

The activities element of the BMCS includes the key activities that are core to the organization. From an economic standpoint, this represents the key activities for (economic) value creation, portrayed within the company, such as marketing, production, or logistics [13]. The environmental dimension of the BMCS focuses on the core activities that generate environmental impacts, particularly production, similarly to the production element of the environmental layer within the triple layer business model canvas [11]. Included in the activities element is the organization governance, originally introduced in the triple layer business model canvas as one element within the social layer that describes the organizational structure and decision-making strategies of the organization [11].

The resources element in the Osterwalder and Pigneur (2010) business model canvas [13] represents the key resources for an organizations' (economic) core activities. Key resources can be physical, financial, or human. From an environmental standpoint, this element describes the resources having an environmental impact. This entails the raw materials and equipment used in manufacturing systems. The social dimension of the canvas focuses on the human resources (employees) and their relationship with the company (also presented as one element of the social layer of triple layer business model canvas of Joyce and Paquin [11]).

The output related stakeholders' element is an extension of the customer segment originally proposed by Osterwalder and Pigneur [13]. It generalizes the customer's element to a broader concept, allowing the incorporation of stakeholders affected during the use and end of life phases in a life cycle perspective, centered in the product or service. In fact, in the environmental dimension and, according to the LCA categories, the main stakeholder is the planet involving people and ecosystems. From a social perspective, this element represents the stakeholders impacted by the business model, which include both end-users and the society involved in the downstream phases of the product's life cycle. The social perspective focuses on the impact of the organization on society, considering how certain actions can positively or negatively influence society [11].

While the economic dimension of the output-related stakeholders relationship element is typically focused on the relationships with the output stakeholders (especially customers) and on the resources to achieve it, the environmental aspects include also the impact on ecology, namely by green policies. The social aspects regard the relation between the company and society. This may include activities such as developing integrative practices amongst different cultures, areas, or nations, or promoting sustainable consumption habits.

The channels element of the business model canvas focuses on how the product or service is delivered to customers [13]. This component comprehends both the physical (transportation means) and economic (selling method) distribution channels. Typically, organizations focus on selling strategies, such as direct sales through a website/store or indirect through retailers. The environmental dimension of this component is dominated by the physical delivery of the functional value in the form of a product or a service. It considers both transportation methods and distance travelled. The social dimension maps the relations with people involved in the distribution channels. This should help to study how different distribution channels can impact the distribution side of the supply chain, particularly considering the fraction of society directly affected by it. However, it is challenging to identify social and environmental-related relationships as well as channels, and it seems to depend on the characteristics of the business model, whether these elements need to be analyzed in detail in terms of all three pillars of sustainability, or only in terms of the economic pillar.

Finally, the burdens element includes the negative environmental, social, and economic impacts resulting from the company's business model. The benefits, on the other hand, are the positive impacts generated by the company with respect to the three dimensions of sustainability.

All the aspects outlined in the section above, from both the input and output side, must be taken into account when analyzing and defining all the burdens and benefits in each sustainability pillar of analysis. The Business Model Canvas for Sustainability is a mapping framework, and in it, the characteristics of a business model are only listed, without a quantitative assessment. This is performed in the following step of a comprehensive sustainability assessment analysis, with a model proposed in the following section.

3. Model to Map and Assess Business Models Using the Business Model Canvas for Sustainability

The BMCS (or the business model canvas in general) is often used within the business model development process, e.g., to visualize rough business model ideas at the beginning of the development process (for the business model development process see Wirtz (2013) [23] or Schallmo (2013) [24]). To assess the profitability of business model ideas, business model design options and whole business models, it is also necessary to include evaluation activities within the business model development process [23]. To structure the development and evaluation process of business models or model ideas, the authors propose a new model, based on the procedure model developed by Götze and Rehme (2013) [25]; Rehme et al. (2015) [26]—which is extended to include all dimensions of sustainability. The model (shown in Figure 2) comprises a combination of different tools and models supporting different steps. The identification of business model ideas, the elaboration and preselection of business models up to their final sustainability evaluation and implementation. The first step in this perspective is the identification of business model ideas [26]. For the following step, the elaboration of business models, the authors suggest using the BMCS to conceive and describe the elements of the selected business models. After the elaboration of the selected business models, Rehme et al. suggest a double-stage assessment process [26]. The first step is the preliminary evaluation of business models, e.g., preselecting promising models. For the economic consideration, Rehme et al. [26] suggest using the assessment criteria derived from the resource-based view of strategic management: eligibility to provide benefit, heterogeneity/non-inimitability, permanence, and the ability to generate (economic) profit (more about the resource-based approach and the criteria: see e.g., Barney (2013) [27], Rehme et al. (2015) [26]). In a sustainability context, the benefits can refer to economic as well as environmental and social issues. Analogously, the concept of "profit" might be extended to all sustainability dimensions. The criteria can be weighted and evaluated by using different methods: One option would be to describe their relevance and characteristics solely verbally. Another approaches would be to exclude business model alternatives systematically by an incremental survey of the criteria (e.g. by applying Barney's (2013) VRIO logic [27]) or using scoring models for a comparative evaluation of the outcome of the criteria, both originally proposed by Rehme et al. [26]. The ranking method proposed by Rehme et al. classifies alternatives by comparing them to the baseline using: "+" (better performance), "++" (much better performance), "−" (worse performance), "−−" (much worse performance), and "o" (similar performance) [26].

The second step of the double-stage assessment is the detailed evaluation of the remaining business model alternatives. The economic, environmental, and social burdens and benefits mapped in the BMCS must be assessed through methodologies that consider a life cycle perspective, being that the BMCS has a life cycle perspective too. In this model, the Life Cycle Costing (LCC) is proposed for the economic dimension, the Life Cycle Assessment (LCA) for the environmental dimension, and the Social-Life Cycle Assessment (SLCA) for the social dimension. These are the most common methodologies for assessing each dimension in a life cycle perspective. For the sake of simplicity as well as consistency, the dimension-specific evaluation should use a common base data and assumptions where the same objects are relevant.

The existing procedure model includes LCC in the form of a profitability calculation that shows the monetary consequences of the selected business model(s). Therefore, the well-established Net Present Value method is suggested [26], as it is proposed as a suitable method of conducting life cycle costing, especially for products or resources [28,29]. It is based on the principle that the economic performance of a project is expressed as a sum of the future cash flows (in and/or out), discounted with a given interest rate, and that it can be applied over a period of time, which allows for an evaluation at different project stages [30]

In terms of the environmental assessment, after its introduction in the late 1960s and early 1970s [31], LCA has become the predominant method to assess life cycle-related environmental sustainability in the recent years [32]. Additionally, it is a well-structured method, as its procedure is determined in an ISO-standard [33]. Therefore, LCA is suggested as a methodological framework to assess environmental impacts throughout the life cycle of a product or service. By focusing on a life cycle perspective, LCA allows for an holistic evaluation of the business model environmental sustainability, considering not only impacts directly resultant from its activities, but also the impact of down or upstream activities that may occur as a result. An LCA analysis consists of the following four phases: definition of the goal and scope, inventory analysis, assessment of impacts, and interpretation [33]. The impacts can be assessed with different methods (e.g., ReCiPe) focusing on one or more environmental impacts, in the form of impact categories [34]. These categories refer to, amongst others, climate change, resource depletion, or human health [35].

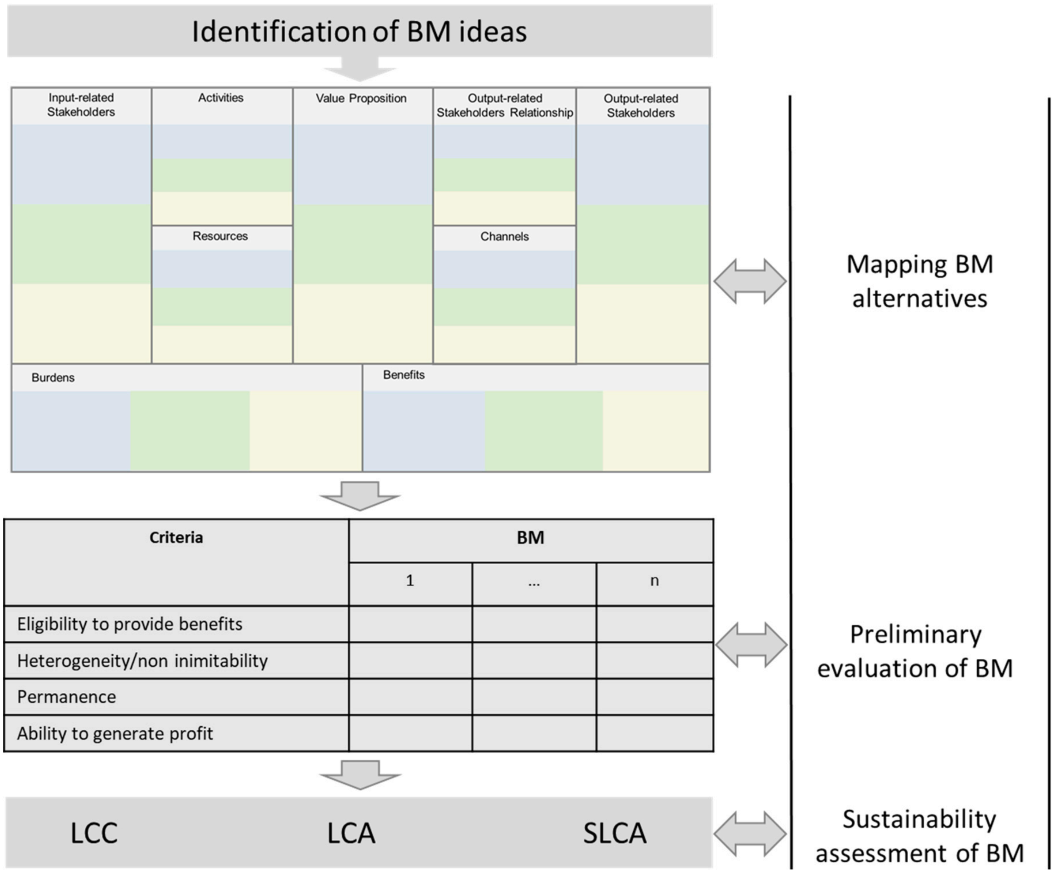


Figure 2. Procedure model to map and assess business models using the business model canvas for sustainability (BMCS) (blue—economic aspects; green—environmental aspects; yellow—social aspects). Based on Götze, U., Rehme, 2013 [25]; Rehme et al., 2015 [26].

Regarding the social assessment, it is suggested to conduct the Social LCA (S-LCA), seen as it expands the environmental LCA to social aspects. Thus, it is life cycle oriented too and can therefore either be conducted as an addition of environmental LCA or independently. As the focus of S-LCA differs from the one of environmental LCA (here, mainly physical quantities are the input needed for the assessment), more information regarding the organizational aspects are in focus (UNEP, 2009, for more similarities and differences between environmental LCA and S-LCA see UNEP, 2009, p. 37 ff. [36]). To conduct S-LCA for business models, the authors propose to follow the UNEP/SETAC guidelines for social impact assessment [36], dividing the stakeholders in five groups: (1) workers, (2) society, (3) local community, (4) value chain actors, and (5) consumers. For each stakeholder group, a set of sub-categories is used to calculate social impacts. Furthermore, each sub-category is described by a number of quantitative/qualitative indicators. The performance of a certain business model is assessed for each indicator, measuring the performance of the object under consideration relative to the country's/sector's/industry's current situation (see UNEP, 2009 for information about the categories and sub-categories [36]). Although UNEP/SETAC guidelines offer a standard basis for analysis, there is not a consensus on how to quantify the impact or performance with regards to the different categories and sub-categories; therefore, various authors present different approaches. Padilla-Rivera et al. [37] proposed a quantification method based on performance reference points, which has later been used by Rivera-Huerta et al. [38]. Similarly, Franze and Ciroth [39] proposed a rating system based on the UNEP/SETAC guidelines, with grades ranging from 1 to 6, both to assess performance and to evaluate impacts of each subcategory on the indicators, which was later applied by Ribeiro et al. [40], to assess the social impact of an innovative business model to fight food waste. To enable a more detailed evaluation of the social impacts, it is suggested here to apply a utility value analysis. Utility value analysis seeks to analyze a number of usually complex alternatives, with the aim of ordering them according to the preferences of the decision-maker in a multi-dimensional target system. The ordering is carried out by calculating utility values for the alternatives. In this case, the so-called utility values represent the social value of business models. In utility value analysis, multiple target criteria are weighted according to their importance to the decision-maker. The ability of the different alternatives (here, the business models under consideration) to fulfil each criterion is measured and a corresponding partial utility value is given. The weighted partial utility values are summed to obtain a total value for every alternative–the utility value. For any one alternative, the aggregation of (weighted) partial utility values allow unfavorable results on one target measure to be compensated by better results on others. If certain criteria have minimum requirements, that fulfilment has to be assured before carrying out a utility value analysis [30].

As the economic, environmental, and social assessments lead to individual results, it should be discussed whether they can and should be aggregated to get an integrated assessment of sustainability. Although this paper does not suggest an aggregation method, other authors have tried to combine economic, social, and environmental assessments. To enable a significant aggregation, a common data and system basis is mandatory, especially for an enhancement of consistency of the assessments [41]. As in this case, decisions about different business models with more than one target (here: economic, environmental, social) are focused on, methods of multi-attribute decision-making can be applied [30,42]. Examples of multi-attribute decision-making approaches are the utility value analysis, that was already suggested for the social assessment, and the analytical hierarchy process (for an overview about multi-attribute decision-making approaches see Götze et al., 2015, p. 166 [30]). These approaches are characterized by having a common target value that includes all three dimensions, which can be used to assess the sustainability of the considered object (in this case the business model) [41]. Alternatively, or additionally, one can use graphical approaches to interpret the integrated contribution to sustainability. One example is the ternary diagram that reflects which alternatives are preferable in dependence of the weightings of the different dimensions of sustainability [40,41]. Furthermore, a third alternative is to use monetary value indicators to aggregate results, namely with the Social Net Present Value method [43,44] and the Social Return on Investment method [40,45].

4. Additive Manufacturing Case Study

To illustrate and test the proposed methods, this section contains a case study focused on developing and assessing a new business model resultant from the introduction of additive manufacturing technology in aircraft Maintenance, Repair, and Overhaul (MRO). Traditionally, aeronautic MRO companies focus their activity on replacing parts, some outsourced and some produced internally. The new business model, explained in more detail in the next sub-section, adds component design optimization enabled by additive manufacturing as a value-added service.

Additive manufacturing is defined as "a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies" [46]. One of the most frequently mentioned opportunities created by additive manufacturing is the distribution of production. Distributed manufacturing results from moving production from centralized facilities to mini-factories closer to the consumer [47,48]. According to Walter et al. (2004), additive manufacturing will allow companies to replace central warehouses with central data repositories, which in turn will support distributed manufacturing [49]. This has the potential to reduce inventory costs and to simplify the supply chain by improving logistics and reducing transport, resulting in lesser environmental impacts. Furthermore, one of the key characteristics of additive manufacturing is the ability to produce complex parts with few design constraints compared to conventional processes. This characteristic is particularly relevant as it allows designers to optimize design, thus improving performance [50]. In fact, various studies focus on leveraging additive manufacturing's opportunities to reengineer parts, thus reducing aircraft weight and consequently fuel consumption. This innovation has clear benefits for society, both from economic and environmental/social standpoints [50,51].

By integrating decentralization of production and reengineering parts for weight optimization as a service, maintenance repair and overhaul companies have the opportunity to shift towards product-service business models with the promise of adding more value to their customers by reducing weight, which is expected to result in fuel savings [52]. There are several real cases in which additive manufacturing is already certified for aircraft parts, and this is a growing trend [53,54]. This therefore offers opportunities for MRO companies to acquire additive manufacturing capabilities regarding not only production but also part design optimization. In fact, the case study presented in this paper focuses on an aircraft MRO company with the intention of opening a new business segment to respond to the demand of these new parts. In the following section, the application of the proposed model to this case study is presented.

The case study follows the procedure method proposed in section three; therefore, it was developed in three stages: mapping business model alternatives, preliminary assessment, and finally, sustainability assessment. The first stage used the Business Model Canvas for Sustainability to map the new business model by highlighting the changes from the existing one. Afterwards, the model was subjected to a preliminary assessment based on information from scientific/technical literature and opinions from experts both from academia and from MRO companies. Finally, an assessment of environmental, economic, and social impacts was performed, using life cycle assessment, net present value, and social life cycle assessment, as proposed in Section 3. The last part of the study was conducted using industrial data, gathered with additive manufacturing component suppliers and aeronautic MRO companies.

4.1. Mapping Business Model Alternatives

The changes in the company's business model are mapped using the BMCS illustrated in Figure 3, focusing on exploring the opportunities offered by additive manufacturing. The adoption of additive manufacturing drives changes in the value activities and consequently in the value proposition.

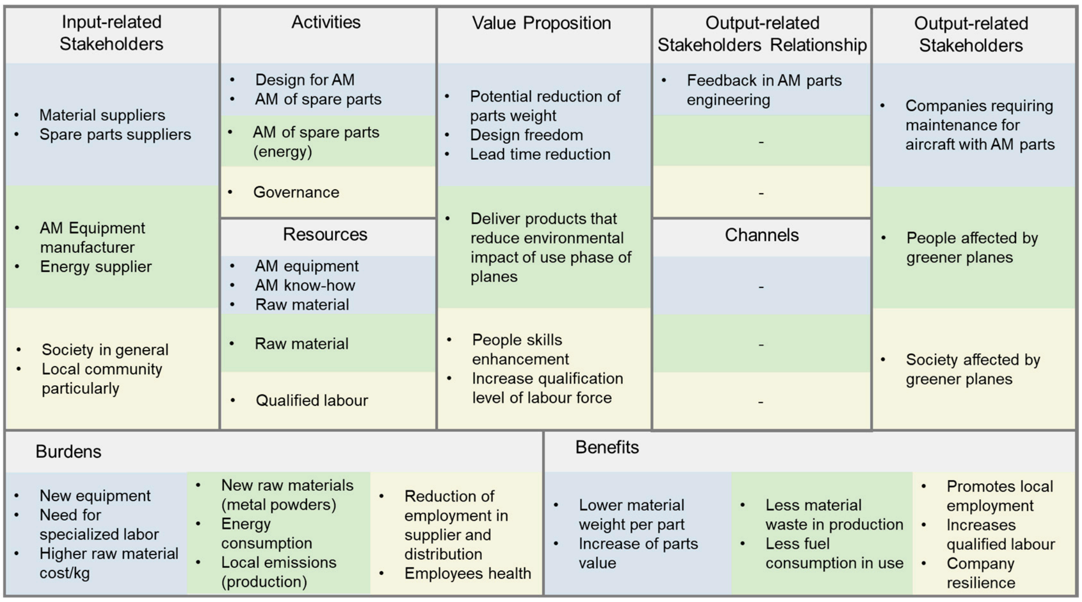


Figure 3. Business Model Canvas for Sustainability applied to an aircraft maintenance company (blue—economic aspects; green—environmental aspects; yellow—social aspects).

The blue color in the BMCS is used to map the traditional economic aspects of the business model. The value proposition of this business model is to offer the production of optimized and, therefore, substantially lighter parts, to benefit the client during the use phase. The model focuses on producing optimized components to take advantage of the additive manufacturing processes. Naturally, this implies the utilization of specific equipment and know-how [55]. To produce spare parts using additive manufacturing, the company acquires raw material in the form of powder, instead of machining material blocks [56]. There is not only a change in the raw material suppliers, but also the potential elimination of spare part suppliers [57]. The major novelty in the economic dimension is the inclusion of output related stakeholders, which are the companies benefitting from weight reduction during the aircraft use (fuel cost saving) and the people potentially affected in the future by lower fares due to lower CO_2 emissions [58,59]. By introducing design optimization as a service, the relationship with customers (output related stakeholders) is significantly changed, with customer feedback playing a crucial role in the engineering process [60]. The resource base is enhanced by new know-how and competencies which might be future core competencies. The distribution channels are not affected by the change in business model. This is true in the three dimensions of the BMCS.

The environmental dimension (green color), which serves as a basis for the environmental impact assessment, reflects the aspects of the business model with potential environmental burdens/benefits. The environmental value proposition is the delivery of products that reduce fuel consumption and the correspondent emissions during aircraft use [61]. There is no significant difference in the environmental impact of raw material acquisition and transport. However, the design optimization of parts and consequent material reduction will have a positive impact on material consumption [50]. The main change in impact within the company is the introduction of a new activity (additive manufacturing). The environmental impacts resulting from that change are the machine itself and the new manufacturing process (with influences on energy, resources, and emissions). One of the key contributions of additive manufacturing to environmental sustainability is the excellent material usage ratio [62], which implies less raw material waste during production. This is particularly relevant in the aerospace sector due to its generally low buy-to-fly material ratios [6]. One of the main benefits of additive manufacturing introduction occurs during the use phase, where weight reduction through design optimization has a positive impact in airplane fuel consumption [51].

Finally, the social dimension of the business model is mapped in yellow. The social value proposition is to increase the qualification level within the workforce [63,64], thus promoting the enhancement of local people skills and potentially decentralizing production. Upstream, the local community is the most affected one. By creating a need for qualified labor, it is expected that the company will have a positive impact on promoting education in local communities. However, there is the possibility of a negative impact related to the reduction of employees needed in the existing spare parts suppliers and distributors. Overall, it is expected that the additive manufacturing enabled business model will have a positive social impact on society in general, as a driver for technology development. Furthermore, it is expected that workers will also benefit from improved working conditions granted by safer manufacturing techniques [64]. Regarding the output stakeholders, the society will benefit from greener planes considering the health implications of CO_2 emissions from airplane operation [65].

4.2. Preliminary Evaluation of Business Model

The preliminary evaluation of the business model focuses on the comparison between the existing business model and the new one, with the adoption of additive manufacturing and part optimization services. Each business model is assessed according to the proposed criteria (see Table 2), setting the current business model as the baseline, and evaluating it as normal. The new business model is assessed by comparison to the baseline. It can be considered an improvement (+) or a deterioration (−) of the traditional business model, regarding each criterion. Furthermore, it can have the same expected performance, which results in a "o" evaluation. The new business model is potentially better regarding the eligibility to provide benefits to the customer, as it allows improvements in the product performance. Regarding heterogeneity, the adoption of additive manufacturing increases resources within the company, both tangible (equipment) and intangible (expertise), and is therefore considered above normal in this criterion. Permanence/non imitability is a weak point of additive manufacturing technology, as it is relatively simple to imitate and replicate a part. Furthermore, it is expected that other competitors will also adopt this technology in the future. Therefore, this is evaluated as a deterioration. Finally, the new business model shows higher potential for profit, as it is possible to use less material, thus contributing to fuel consumption reduction and consequential cost savings for the consumer. This added value offer can be leveraged to increase service price, therefore contributing to higher profit margins.

Table 2. Preliminary evaluation of business model alternatives.

Criteria	Business Model	
	Current	**Additive Manufacturing Adoption**
Eligibility to provide benefits	o	+
Heterogeneity	o	+
Permanence/non inimitability	o	−
Ability to generate profit	o	+

4.3. *Sustainability Assessment of Business Model*

In this section, the results of the sustainability assessment are shown. The economic and environmental evaluations are based on an illustrative part, a generic bracket, to show the potential impact/benefit from weight reduction. The part was reengineered for additive manufacturing using topological optimization and later manufactured using a Renishaw AM 400 selective laser melting machine. All data regarding industrial processes was collected in an industrial context with a supplier of additive manufacturing parts. Originally manufactured by forging, the part's topological optimization for additive manufacturing showed the possibility to reduce 18% of the weight. Furthermore, information about the MRO company, its current practices, the used part, and relevant cost elements were provided by a Portuguese MRO company.

Finally, while both economic and environmental assessments only consider the burdens/benefits of one part, the social assessment focuses on the entire business model and its impact on the different stakeholder groups affected.

4.3.1. Economic Evaluation

The economic evaluation is based on the Net Present Value (NPV) method, considering short and medium timeframes (1 and 5 years) and an interest rate of 10%. The cost variations represent the MRO company perspective and focus on logistics (storage) and production. Furthermore, the benefits from weight savings during operation were considered as potential value increase in selling price. The MRO company's revenue results from the installation of spare parts. Production costs were compared for both, forging and selective laser melting, assuming non-dedicated machines. The costs for both processes take into account machine, operator, material, consumables, and energy, as shown in Table A1. Storage costs were provided by the MRO company and represent 10% of the part's cost, which currently amounts to 12.8 €/part. The additive manufacturing process (162.3 €) is considerably more expensive than the conventional process (128.7 €); however, the potential reduction in delivery times allows for 50 % savings in storage costs (Table 3).

Table 3. Cost comparison between parts manufactured using additive manufacturing and forging.

Process	Prod. Cost [€]	Storage Cost [€]	Total Cost [€]
Additive manufacturing	162.3	6.4	168.7
Forging	128.7	12.7	141.4

Annual fuel savings were calculated for one average European route (Lisbon to Berlin), using an Airbus A319, a common aircraft for this type of route. The data used for this calculation were that the route was 3.5 h long and 2.313 km in distance. These values are in accordance with the Portuguese airliner, TAP Air Portugal. Furthermore, TAP states that the aircraft doing this route travels for 4800 annual flight hours.

The analysis of the fuel consumption was then carried out using data from the Civil Aviation Authority's Flight Planning Manual [66] for the aircraft under consideration. Using this method, the initial fuel required and the fuel consumption in each of the flight phases (climb, cruise, descend) were calculated. Notice that the aircraft weight changes during the flight as a result of fuel consumption. Therefore, the process calculating the weight is iterative, each phase of the flight depends on the overall weight at the end of the previous (e.g., the weight at the beginning of the cruise phase is the initial weight minus the fuel mass used in climbing). Results show a potential annual cost saving of 16 € per part installed in the airplane. The assumptions for this analysis can be found in Table A1.

Although weight savings result in clear benefits for the flight operator, it is not clear how much of those benefits can be internalized by the MRO company. To account for this uncertainty, a sensitivity analysis comprised of three scenarios was performed to analyze the impact of weight savings. In the first case, the annual fuel savings were fully transferred to the MRO company. According to this scenario, the MRO company would be able to increase the price to the same amount as the fuel savings over the period of 5 years. The second and third cases consider half and no transfer, respectively. As shown in Table 4, the net present value is significantly higher with the increase in profit transfer from the use phase. In fact, the business model is only economically viable if the company is able to maintain 50% of profit transfer rate in a five-year period. Results consider only the increase in production cost in year 0, followed by the combination of storage cost reduction and fuel savings in consequent years (1 to 5).

Table 4. Investment appraisal analysis of the business model.

Profit Transfer Rate (Use Phase)	ΔProd. Cost [€]	ΔStorage Cost [€]	ΔAnnual Fuel Cost [€]	Δ Net Present Value (NPV) 1y [€]	ΔNPV 5y [€]
100%			−16	−13	34
50%	+34	−6	−8	−19	3
0%			−0	−27	−27

It is important to notice that this analysis only considers an example of one spare part installed in one aircraft to demonstrate the potential benefits of the new business model. Recent studies show that an average aircraft can have between 250 to 500 kg of metal auxiliary parts, which could be suitable for additive manufacturing production and consequent weight optimization [51]. Applying the same weight optimization (18%) to 500 kg of auxiliary spare parts would reduce 90 kg of the aircraft weight, which results in annual savings of around 11.674 €. Distributing the 500 kg over 1.438 parts equals to the one showed previously, the net present value for a lifetime of 5 years would increase to 19.481 €. Furthermore, the 18% weight reduction considered in this analysis is conservative, with recent studies showing reductions of up to 80% [52].

4.3.2. Environmental Evaluation

The life cycle assessment quantifies the environmental impact and is focused on the same spare part example as the economic analysis. The carbon footprint indicator was computed using the ReCiPe Midpoint (H) V1.11/Europe Recipe H method with the Eco Invent 3 database in SimaPro.

This life cycle analysis focuses the full life cycle of the spare part from production to end-of-life. The functional unit was defined as one spare part installed and running in the aircraft. The impact assessment is performed for one and five years, using the same assumptions as in the economic analysis. Furthermore, it is assumed that the part installation process is not changed by the new business model, therefore its environmental impact remains the same. The relevant life cycle phases are production, transport, use, and end of life. In the production phase, only the material and energy consumption were considered. In both cases, the material consumption includes the steel needed for the spare part and the waste material from the processes (additive manufacturing (8%) and forging (20%) [67]). Energy consumption is estimated following the specific consumption models proposed by Ciceri et al. [68] for forging and by Baumers et al. [69] for additive manufacturing. The current spare part supplier is located in Germany; however, the new business model focuses on producing in house, therefore eliminating transport. The end-of-life process remains the same in both cases (recycling). Finally, the use phase considers the scenario previously described in the economic analysis, with the differences in impact resulting from the weight optimization.

The life cycle assessment reveals that the use phase is responsible for most of the environmental impacts. Table 5 presents the comparison in equivalent CO_2 emissions between the two cases. Results show that even for only one year of use the adoption of additive manufacturing has a positive impact of 210 kg CO_2eq/part, considering the balance between the increase in production impact and the savings from use, end-of-life, and transport. These results mean that for each part optimized and produced using additive manufacturing, there is a potential for significant reduction of CO_2 emissions over the period of one year. As expected, considering 5 years use and the correspondent fuel savings, the environmental benefits largely outweigh the increase in environmental impacts during production.

Table 5. Comparative impact assessment of the new business model by comparison with the conventional, for one part during one and five years of use.

Life Cycle Phase	Resource	ΔCO_2 Equiv. [kg] (1 Year)	ΔCO_2 Equiv. [kg] (5 Years)
Production	Materials (Tooling Steel) and energy	+10.66	+10.66
Transport	Air transport	−0.89	−0.89
Use	Air transport	−221.74	−1.108.68
End-of-life	Recycling	+0.13	+0.13
Total		−211.84	−1.098.78

4.3.3. Social Evaluation

The application of the Social Life Cycle Assessment method follows the UNEP/SETAC guidelines for social life cycle assessment [36] which indicators are in Table A2. In this method, each target criterion was weighted under the assumption that every category considered has the same importance. This is a simplification and can be adapted to each company and its strategic goals.

The performance of each business model regarding the target criteria was then compared and ranked with 1 if it performed better, 0 if worse and 0.5 if similar (see Table 6). As illustrated in the case study description, the social value proposition is to enhance people skills and qualification level of the company's workforce. Traditional MRO is carried out by maintenance technicians and machining operators, whereas additive manufacturing requires a different set of specialized workers, skilled in 3D modelling and topological optimization. There is a clear difference in salaries between operators/technicians and specialized workers, such as the ones required for additive manufacturing driven MRO business models. This expected increase in salary leads to a better social performance. The relation between metal additive manufacturing and worker's health and safety is a recent topic. Generally, additive manufacturing introduces a set of health risks related to metal powder inhalation [32]. Considering the additional risks of additive manufacturing, the new business model has a slightly worse performance than the conventional, which is reflected by a partial utility value of 0.

The new business model has a positive impact for local communities. This positive change stems from the decentralization opportunities of additive manufacturing, combined with the business model ability to generate local employment [70]. By capturing spare part production for the company, there is a clear decentralization of production from big factories to local facilities. Naturally, moving production closer to the customer (airliners) promotes local employment and plays a key role in reducing migration rates. Furthermore, the stakeholder group "society" benefits from technology developments and its contribution to economic development, associated with a clear public commitment to sustainable air transportation. Introducing an innovative, autonomous process in the aeronautic industry is an undeniable contribution to technological development. As a fairly recent manufacturing technique, additive manufacturing development is dependent on early adopters. The creation of a new business model that leverages additive manufacturing capabilities will drive an increase in demand, which will lead manufacturers to advance additive manufacturing technology. The advances are expected to lead to faster and more affordable machines [6]. By offering a new part optimization service, the company commits to deliver lighter parts for the aeronautic industry, therefore committing to contribute to fuel savings in air transportation.

Table 6. Partial utility value for the original and the additive manufacturing driven business model.

Target Criteria / Alternative	Fair Salary	Health and Safety	Decentralization and Migration	Local Employment	Public Commitment to Sustainable Issues	Contribution to Economic Development	Technology Development	Supplier Relationships	Respect of Intellectual Property Rights	Feedback Mechanisms
Additive manufacturing	1.00	0.00	1.00	1.00	1.00	1.00	1.00	0.50	0.00	1.00
Forging	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.50	1.00	0.00

A big concern with additive manufacturing adoption is the respect of intellectual property rights [71]. Although it is not expected that the company violates any intellectual property rights by adding optimization as a service and additive manufacturing as a production method, there is an increased risk of the technology being a facilitator of property rights infringement [8]. Additionally, additive manufacturing is expected to change supplier relationships, as companies start manufacturing products that would otherwise be bought. One possibility is the supplier moving from delivering spare parts to selling 3D files for those parts.

The changes regarding the stakeholder group "customers" are centered in the feedback mechanism necessary to operate a spare part optimization service. In order to assure compliance with airliner requirements and the maximum weight saving without compromising durability or usability, the company has to integrate customers in the design process. In this regard, the business model has a much better performance than the conventional, where customer feedback is limited to satisfaction evaluation. This change affects mainly the governance of companies.

Generally, the introduction of additive manufacturing methods in aircraft MRO appears to have a significantly better performance than conventional methods; however, there are some concerns that have to be taken into account. While most subcategories are benefited by this business model, worker's health and safety and the respect of intellectual property are critical issues of additive manufacturing regarding social sustainability.

Finally, the total utility value of each business model alternative was calculated by combining the partial utility and the relative weight of each category. The aggregated utility results show a better performance of the new business model (additive manufacturing). The adoption of additive manufacturing in this case has a higher utility (0.75 > 0.25) from the perspective of the decision-maker.

5. Conclusions

This paper contributes to the theory of business modelling and sustainability as well as to the field of additive manufacturing. The theoretical contribution comprises the development of a sustainability-related business model concept based on the established Canvas approach (the "Business Model Canvas for Sustainability") and a procedure model to evaluate business models with respect to their contribution to all dimensions of sustainability. This model includes the suggestion to use utility value analysis for assessing the social dimension of sustainability—an evaluation task for which hardly any established methods exist until now. The application of the sustainability-related Canvas as well as the evaluation methodology in an industrial case revealed their ability to generate significant results in a structured and transparent way.

Concerning the field of additive manufacturing, its potential to contribute to all dimensions of sustainability was shown for the example of a company providing MRO services for aircrafts. As expected, moving to distributed manufacturing of spare parts does not offer MRO companies the opportunity to add value to their customers; however, it unlocks the opportunity of optimizing spare part weight as an added value service. Furthermore, it appears to have significant benefits both for society and the environment. The first results from increased workforce qualification, creation of local employment, and higher control over salaries. Meanwhile, the environmental dimension benefits from reduced transport of spare parts between factories, lower raw material consumption and waste, and fuel savings during aircraft operation.

However, theoretical considerations as well as the experience from the industrial case point to some methodical challenges: amongst others, the structure and elements of the suggested BMCS, the acquisition and the uncertainty of the necessary data especially in the early phases of business model development, the systematic development/elaboration of the business model (variants) towards contributions to all dimensions of sustainability as well as the methodology of assessing the social dimension raises difficulties. Against this background, especially the uncertainty of data used, the results concerning the potentials of additive manufacturing have to be interpreted carefully.

To enable handling the challenges mentioned above, the methodical elements suggested need further practical application and validation as well as refinement. The latter should address, amongst others, the Canvas structure, data collection in early phases of business model development, a methodology to systematically develop business models towards (all dimensions of) sustainability, and a deeper elaborated evaluation of social sustainability. Regarding the typical lack of data in early stages of a business model, this can be overcome by the continued application of this procedure throughout the business life. It should also include strategies of knowledge management and the use of new possibilities of IT such as big data. Regarding methodological challenges, the procedure model may also be developed to include in the preliminary assessment phase criteria with the scope on the three pillars of sustainability. Furthermore, the social assessment is, unlike the other dimensions of sustainability, in a development phase, with a large number of new impact assessment methods being published nowadays. Therefore, it is important to further investigate possible alternative methods for the social assessment. Finally, the potential of additive manufacturing and the hurdles of its technological and market success (including the risk of imitation of a company's individual additive manufacturing business model) should be analyzed in more depth in order to establish (sustainable) value chains based on this technology.

Author Contributions: Conceptualization, G.C. and K.H.; Methodology, G.C., K.H., I.R. and U.G.; Validation, G.C., K.H., I.R. and U.G.; Investigation, G.C. and K.H.; Formal Analysis, G.C.; Visualization, G.C. and K.H.; Writing—Original Draft Preparation, G.C., K.H., I.R. and U.G.; Writing—Review & Editing, G.C., K.H., I.R. and U.G.; Resources, I.R. and U.G.; Supervision, I.R. and U.G.; Project Administration, I.R. and U.G.; Funding Acquisition, I.R. and U.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors acknowledge Fundação para a Ciência e a Tecnologia (FCT), through IDMEC, under LAETA, project UIDB/50022/2020. Also acknowledge the support of FCT for project KM3D (PTDC/EME-SIS/32232/2017) and FCT grant (ref: PD/BD/140820/2018). This work was carried out as part of the program "PPP Portugal", project "Enhancement of Life Cycle Engineering Methodology by Integration of Management-related Methods and its Application to Complex Systems", and is partially supported by the DAAD with funds of the German Federal Ministry of Education and Research.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Data considered in the economic analysis.

	Variable	Value	Units	Source
Data used to calculate part cost	Building square meter price	30	[€/m^2]	Gathered in industrial context, in collaboration with, "Hypermetal-Metal Additive Manufacturing"
	Discount rate	10	[%]	
	Electricity price	0.158	[€/kWh]	
	Operator hourly cost	16	[€/h]	
	Data preparation time for the first batch	3	[h]	
	Data preparation time for the next batches	0.5	[h]	
	Building space	3	[m^2]	
	Software cost	0	[€]	
	Hardware cost	1500	[€]	
	Software renewal cost	0	[€/year]	
	Hardware renewal cost	0	[€/year]	
	Building depreciation time	30	[years]	
	Software depreciation time	3	[years]	
	Hardware depreciation time	5	[years]	
	Setup time	0.5	[h]	
	Cost of preparing the base plate	20	[€]	
	Part mass	0.285	[kg]	
	Price of raw material	25	[€/kg]	
	Material loss factor	8	[%]	
	Price of gas cylinder	60	[€]	
	Price of a filter	30	[€]	
	Number of batches per gas cylinder	6	[-]	
	Filter duration	100	[h]	
	Maintenance cost	0	[€]	
	Machine power	0.4	[kW]	
	Machine initial price	500,000	[€]	
	Machine depreciation time	10	[years]	
	Area occupied by the machine	4.5	[m^2]	
	Safety area around the machine	18	[m^2]	
	Scanning Time	42.5	[h]	
Data used to calculate weight and cost savings	Aircraft	A319	[-]	Gathered from existing literature: (Tap website, correct as of July 2020) Gathered from existing literature: [72–74]
	Flight time	3.5	[h]	
	Distance	1249	[NAM]	
	Annual flight hours	4800	[h]	
	Airport altitude	374	[ft]	
	Aircraft weight	62,000	[kg]	
	ISA deviation	−5 to 5	[°C]	
	Cruise speed	424	[kt]	
	Cruise altitude	37,000	[ft]	
	Fuel price	0.23	[€/L]	

Appendix B

Table A2. Indicators considered in the Social Life Cycle Assessment (S-LCA) study (UNEP Setac, 2009 [36]).

Stakeholder	Sub-Categories	Indicator
Workers	Fair salary	Specification of living wage and minimum wage in the country
		Wage level of the worker with lowest income and description of payment performance of the sector/enterprise
	Health and safety	Description of potential main origins of danger and protection measures
		Description of reported violations
		Accident rate of the country/sector/organisation
		Presence of a formal policy regarding health and safety
Local Community	Delocalisation and migration	Migration rate of the country/region
		Number of individuals who resettle that can be attributed to the sector/organisation
	Local employment	Percentage of unemployment in the country/region
		Percentage of work force hired locally
		Percentage of spending on locally based suppliers
Society	Public commitment to sustainable issues	Presence of publicly available promises or agreements on sustainable issues and complaints to the non-fulfilment of these commitments
		Implementation/signing of principles or codes of conducts
	Contribution to economic development	Economic situation of the country/region and relevance of the considered sector for the (local) economy
		Contribution of the product/sector/company to economic development
	Technology development	Sector efforts in technology development regarding ecofriendliness
		Involvement of the company in technology transfer projects
		Presence of partnerships regarding research and development
		Investments in technology development
Value chain actors	Supplier relationships	Interaction of the company with suppliers (payment on time, sufficient lead time, reasonable volume fluctuations, appropriate communication, collaboration regarding quality issues)
		Fluctuation regarding suppliers
	Respect of intellectual property rights	Violations of the company against intellectual property rights
Consumer	Feedback mechanism	Presence of feedback mechanisms
		Practices related to customer satisfaction

References

1. Shafer, S.M.; Smith, H.J.; Linder, J.C. The power of business models. *Bus. Horiz.* **2005**, *48*, 199–207. [CrossRef]
2. Bocken, N.; Boons, F.; Baldassarre, B. Sustainable business model experimentation by understanding ecologies of business models. *J. Clean. Prod.* **2019**, *208*, 1498–1512. [CrossRef]
3. Geissdoerfer, M.; Vladimirova, D.; Evans, S. Sustainable business model innovation: A review. *J. Clean. Prod.* **2018**, *198*, 401–416. [CrossRef]
4. Athanasopoulou, A.; de Reuver, M.; Nikou, S.; Bouwman, H. What technology enabled services impact business models in the automotive industry? An exploratory study. *Futures* **2019**, *109*, 73–83. [CrossRef]
5. Morkunas, V.J.; Paschen, J.; Boon, E. How blockchain technologies impact your business model. *Bus. Horiz.* **2019**, *62*, 295–306. [CrossRef]

6. Ford, S.; Despeisse, M. Additive manufacturing and sustainability: An exploratory study of the advantages and challenges. *J. Clean. Prod.* **2016**, *137*, 1573–1587. [CrossRef]
7. Niaki, M.K.; Torabi, S.A.; Nonino, F. Why manufacturers adopt additive manufacturing technologies: The role of sustainability. *J. Clean. Prod.* **2019**, *222*, 381–392. [CrossRef]
8. Hannibal, M.; Knight, G. Additive manufacturing and the global factory: Disruptive technologies and the location of international business. *Int. Bus. Rev.* **2018**, *27*, 1116–1127. [CrossRef]
9. Oyesola, M.; Mathe, N.; Mpofu, K.; Fatoba, S. Sustainability of Additive Manufacturing for the South African aerospace industry: A business model for laser technology production, commercialization and market prospects. *Procedia CIRP* **2018**, *72*, 1530–1535. [CrossRef]
10. Verboeket, V.; Krikke, H. The disruptive impact of additive manufacturing on supply chains: A literature study, conceptual framework and research agenda. *Comput. Ind.* **2019**, *111*, 91–107. [CrossRef]
11. Joyce, A.; Paquin, R.L. The triple layered business model canvas: A tool to design more sustainable business models. *J. Clean. Prod.* **2016**, *135*, 1474–1486. [CrossRef]
12. Lüdeke-Freund, F. Business models for sustainable innovation: State-of-the-art and steps towards a research agenda. *J. Clean. Prod.* **2013**, *45*, 9–19.
13. Osterwalder, A.; Pigneur, Y. *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*; John Wiley & Sons: Hoboken, NJ, USA, 2010; ISBN 9780470876411.
14. Fichter, K.; Tiemann, I. *Das Konzept "Sustainable Business Canvas" zur Unterstützung Nachhaltigkeitsorientierter Geschäftsmodell-Entwicklung*; Rahmenpapier StartUp4Climate AP 3.1.; Oldenburg, Germany; Berlin, Germany, 2015; Available online: https://start-green.net/media/cms_page_media/2015/12/8/Fichter_Tiemann_2015_Sustainable_Business_Canvas_0812.2015.pdf (accessed on 2 November 2020).
15. Jones, P.; Upward, A. Caring for the future: The systemic design of flourishing enterprises. In Proceedings of the RSD3, Third Symposium of Relating Systems Thinking to Design, Oslo, Norway, 15–17 October 2014.
16. Foxon, T.J.; Bale, C.S.E.; Busch, J.; Bush, R.; Hall, S.; Roelich, K. Low carbon infrastructure investment: Extending business models for sustainability. *Infrastruct. Complex.* **2015**, *2*, 4. [CrossRef]
17. Schallmo, D. *Geschäftsmodell-Innovation—Grundlagen, Bestehende Ansätze, Methodisches Vorgehen und B2B-Geschäftsmodelle*, 1st ed.; Gabler Publishing House: Wiesbaden, Germany, 2013; ISBN 978-3-658-00245-9.
18. Teece, D.J. Business models, business strategy and innovation. *Long Range Plann.* **2010**, *43*, 172–194. [CrossRef]
19. Urban, M.; Klemm, M.; Ploetner, K.O.; Hornung, M. Airline categorisation by applying the business model canvas and clustering algorithms. *J. Air Transp. Manag.* **2018**, *71*, 175–192. [CrossRef]
20. Keane, S.F.; Cormican, K.T.; Sheahan, J.N. Comparing how entrepreneurs and managers represent the elements of the business model canvas. *J. Bus. Ventur. Insights* **2018**, *9*, 65–74. [CrossRef]
21. Schoormann, T.; Behrens, D.; Kolek, E.; Knackstedt, R. Sustainability in business models—A literature-review-based design-science-oriented research agenda. In Proceedings of the European Conference on Information Systems (ECIS) 2016, Istanbul, Turkey, 12–15 June 2016.
22. Huijbregts, M.; Steinmann, Z.J.N.; Elshout, P.M.F.; Stam, G.; Verones, F.; Vieira, M.; Zijp, M.; Hollander, A.; van Zelm, R. ReCiPe2016: A harmonised life cycle impact assessment method at midpoint and endpoint level. *Int. J. Life Cycle Assess.* **2016**, *22*, 138–147. [CrossRef]
23. Wirtz, B.W. *Business Model Management—Design—Instrumente—Erfolgsfaktoren von Geschäftsmodellen*, 3rd ed.; Springer Gabler Verlag: Wiesbaden, Germany, 2013; ISBN 978-3834946355.
24. Schallmo, D.R.A. *Geschäftsmodelle Erfolgreich Entwickeln und Implementieren*, 1st ed.; Springer: Berlin/Heidelberg, Germany, 2013; ISBN 978-3-642-37994-9.
25. Götze, U.; Rehme, M. Bewertung innovativer Geschäftsmodelle bei sich wandelnden Wertschöpfungsstrukturen—Analyse-, Prognose- und Gestaltungsrahmen sowie die Anwendung auf die Ladeinfrastruktur für Elektrofahrzeuge. In *Zeitschrift für Die Gesamte Wertschöpfungskette Automobilwirtschaft (ZfAW) Heft 4*; FAW-Verlag: Bamber, Germany, 2013; pp. 15–25.
26. Rehme, M.; Lindner, R.; Götze, U. Perspektiven für Geschäftsmodelle der Fahrstrombereitstellung. In *Entscheidungen beim Übergang in die Elektromobilität*; Springer Fachmedien Wiesbaden: Wiesbaden, Germany, 2015; pp. 409–428.
27. Barney, J. *Gaining and Sustaining Competitive Advantage*, 4th ed.; Pearson Education Limited (Verlag): Harlow, UK, 2013; ISBN 978-1-292-02145-4.

28. Götze, U. *Kostenrechnung und Kostenmanagement*, 3rd ed.; Springer: Berlin/Heidelberg, Germany, 2004; ISBN 978-3-540-35147-4.
29. Žižlavský, O. Net Present Value Approach: Method for Economic Assessment of Innovation Projects. *Procedia Soc. Behav. Sci.* **2014**, *156*, 506–512. [CrossRef]
30. Götze, U.; Northcott, D.; Schuster, P. *Investment Appraisal*; Springer Texts in Business and Economics; Springer: Berlin/Heidelberg, Germany, 2015; ISBN 978-3-662-45850-1.
31. Chang, D.; Lee, C.K.M.; Chen, C.-H. Review of life cycle assessment towards sustainable product development. *J. Clean. Prod.* **2014**, *83*, 48–60. [CrossRef]
32. Rejeski, D.; Zhao, F.; Huang, Y. Research needs and recommendations on environmental implications of additive manufacturing. *Addit. Manuf.* **2018**, *19*, 21–28. [CrossRef]
33. International Organization for Standardization. Environmental Management—Life Cycle Assessment—Principles and Framework (ISO14040:2006). 2006. Available online: https://www.iso.org/obp/ui/#iso:std:iso:14040:ed-2:v1:en (accessed on 2 November 2020).
34. Hauschild, M.Z. Introduction to LCA methodology. In *Life Cycle Assessment: Theory and Practice*; Hauschild, M., Rosenbaum, R., Olsen, S., Eds.; Springer: Cham, Switzerland, 2018; pp. 59–66. ISBN 9783319564753.
35. Rebitzer, G.; Ekvall, T.; Frischknecht, R.; Hunkeler, D.; Norris, G.; Rydberg, T.; Schmidt, W.-P.; Suh, S.; Weidema, B.P.; Pennington, D.W. Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environ. Int.* **2004**, *30*, 701–720. [CrossRef]
36. UNEP Setac Life Cycle Initiative. *Guidelines for Social Life Cycle Assessment of Products*; United Nations Publications: Paris, France, 2010; ISBN 9789280730210.
37. Padilla-Rivera, A.; Morgan-Sagastume, J.M.; Noyola, A.; Güereca, L.P. Addressing social aspects associated with wastewater treatment facilities. *Environ. Impact Assess. Rev.* **2016**, *57*, 101–113. [CrossRef]
38. Rivera-Huerta, A.; de la Rubio Lozano, M.S.; Padilla-Rivera, A.; Güereca, L.P. Social Sustainability Assessment in Livestock Production: A Social Life Cycle Assessment Approach. *Sustainability* **2019**, *11*, 4419. [CrossRef]
39. Franze, J.; Ciroth, A. *LCA of an Ecolabeled Notebook Consideration of Social and Environmental Impacts Along the Entire Life Cycle*; GreenDeltaTC GmbH: Berlin, Germany, 2011.
40. Ribeiro, I.; Sobral, P.; Peças, P.; Henriques, E. A sustainable business model to fight food waste. *J. Clean. Prod.* **2018**, *177*, 262–275. [CrossRef]
41. Meynerts, L.; Götze, U. Life Cycle Assessment Ökologische Bewertung im Rahmen des Produktions- und Logistikmanagements. In *Handbuch Produktions-und Logistikmanagement in Wertschöpfungsnetzwerken*; Corsten, H., Gössinger, R., Spengler, T.S., Eds.; De Gruyter: Berlin, Germany; Boston, MA, USA, 2018; pp. 1210–1242.
42. Reichel, T.; Rünger, G.; Meynerts, L.; Götze, U. Environment-oriented Multi-criteria Decision Support for the Assessment of Manufacturing Process Chains. In *Energetisch-Wirtschaftliche Bilanzierung—Diskussion der Ergebnisse des Spitzentechnologieclusters eniPROD: 3. Methodenband der Querschnittsarbeitsgruppe "Energetisch-wirtschaftliche Bilanzierung" des Spitzentechnologieclusters eniPROD*; Neugebauer, R., Götze, U., Drossel, W.-G., Eds.; Verlag Wissenschaftliche Scripten: Auerbach, Germany, 2014; pp. 85–92.
43. Serrano-Cinca, C.; Gutiérrez-Nieto, B.; Reyes, N.M. A social and environmental approach to microfinance credit scoring. *J. Clean. Prod.* **2016**, *112*, 3504–3513. [CrossRef]
44. Damigos, D. An overview of environmental valuation methods for the mining industry. *J. Clean. Prod.* **2006**, *14*, 234–247. [CrossRef]
45. Watson, K.J.; Evans, J.; Karvonen, A.; Whitley, T. Capturing the social value of buildings: The promise of Social Return on Investment (SROI). *Build. Environ.* **2016**, *103*, 289–301. [CrossRef]
46. ASTM F2792-12a, Standard Terminology for Additive Manufacturing Technologies, (Withdrawn 2015), ASTM International, West Conshohocken, PA, USA, 2012. Available online: https://www.astm.org/Standards/F2792.htm (accessed on 2 November 2020).
47. Turner, C.; Moreno, M.; Mondini, L.; Salonitis, K.; Charnley, F.; Tiwari, A.; Hutabarat, W. Sustainable Production in a Circular Economy: A Business Model for Re-Distributed Manufacturing. *Sustainability* **2019**, *11*, 4291. [CrossRef]
48. Rauch, E.; Dallinger, M.; Dallasega, P.; Matt, D.T. Sustainability in manufacturing through distributed manufacturing systems (DMS). *Procedia CIRP* **2015**, *29*, 544–549. [CrossRef]
49. Walter, M.; Holmström, J.; Yrjölä, H. Rapid manufacturing and its impact on supply chain management. In Proceedings of the Logistics Research Network Annual Conference, Dublin, Ireland, 9–10 September 2004.

50. Tang, Y.; Mak, K.; Zhao, Y.F. A framework to reduce product environmental impact through design optimization for additive manufacturing. *J. Clean. Prod.* **2016**, *137*, 1560–1572. [CrossRef]
51. Huang, R.; Riddle, M.; Graziano, D.; Warren, J.; Das, S.; Nimbalkar, S.; Cresko, J.; Masanet, E. Energy and emissions saving potential of additive manufacturing: The case of lightweight aircraft components. *J. Clean. Prod.* **2016**, *135*, 1559–1570. [CrossRef]
52. Laureijs, R.E.; Roca, J.B.; Narra, S.P.; Montgomery, C.; Beuth, J.L.; Fuchs, E.R.H. Metal additive manufacturing: Cost competitive beyond low volumes. *J. Manuf. Sci. Eng. Trans. ASME* **2017**, *139*, 81010. [CrossRef]
53. Uhlmann, E.; Kersting, R.; Klein, T.B.; Cruz, M.F.; Borille, A.V. Additive Manufacturing of Titanium Alloy for Aircraft Components. *Procedia CIRP* **2015**, *35*, 55–60. [CrossRef]
54. Wilson, J.M.; Piya, C.; Shin, Y.C.; Zhao, F.; Ramani, K. Remanufacturing of turbine blades by laser direct deposition with its energy and environmental impact analysis. *J. Clean. Prod.* **2014**, *80*, 170–178. [CrossRef]
55. Yi, L.; Gläßner, C.; Aurich, J.C. How to integrate additive manufacturing technologies into manufacturing systems successfully: A perspective from the commercial vehicle industry. *J. Manuf. Syst.* **2019**, *53*, 195–211. [CrossRef]
56. Chen, D.; Heyer, S.; Ibbotson, S.; Salonitis, K.; Steingrímsson, J.G.; Thiede, S. Direct digital manufacturing: Definition, evolution, and sustainability implications. *J. Clean. Prod.* **2015**, *107*, 615–625. [CrossRef]
57. Liu, P.; Huang, S.H.; Mokasdar, A.; Zhou, H.; Hou, L. The impact of additive manufacturing in the aircraft spare parts supply chain: Supply chain operation reference (scor) model based analysis. *Prod. Plan. Control* **2014**, *25*, 1169–1181. [CrossRef]
58. Faber, J.; Huigen, T. *A Study on Aviation Ticket Taxes*; CE Delft: Delft, The Netherlands, 2018.
59. CE Delft; Directorate-General for Mobility and Transport (European Commission). *Taxes in the Field of Aviation and Their Impact*; Publications Office of the European Union: Luxembourg, 2019; ISBN 978-92-76-08132-6.
60. Campbell, R.I.; Beer, D.J.; Mauchline, D.A.; Becker, L.; van der Grijp, R.; Ariadi, Y.; Evans, M.A. Additive manufacturing as an enabler for enhanced consumer involvement. *S. Afr. J. Ind. Eng.* **2014**, *25*, 67–74. [CrossRef]
61. López-Castro, J.D.; Marchal, A.; González, L.; Botana, J. Topological optimization and manufacturing by Direct Metal Laser Sintering of an aeronautical part in 15-5PH stainless steel. *Procedia Manuf.* **2017**, *13*, 818–824. [CrossRef]
62. Le Bourhis, F.; Kerbrat, O.; Hascoet, J.-Y.; Mognol, P. Sustainable manufacturing: Evaluation and modeling of environmental impacts in additive manufacturing. *Int. J. Adv. Manuf. Technol.* **2013**, *69*, 1927–1939. [CrossRef]
63. Despeisse, M.; Minshall, T. Skills and education for additive manufacturing: A review of emerging issues. In Proceedings of the IFIP Advances in Information and Communication Technology, Hamburg, Germany, 3–7 September 2017; Springer: New York, NY, USA, 2017; Volume 513, pp. 289–297.
64. Machado, C.G.; Despeisse, M.; Winroth, M.; da Silva, E.H.D.R. Additive manufacturing from the sustainability perspective: Proposal for a self-assessment tool. *Procedia CIRP* **2019**, *81*, 482–487. [CrossRef]
65. Stettler, M.E.J.; Eastham, S.; Barrett, S.R.H. Air quality and public health impacts of UK airports. Part I: Emissions. *Atmos. Environ.* **2011**, *45*, 5415–5424. [CrossRef]
66. Civil Aviation Authority. *CAP 697 Flight Planning Manual*; TSO (The Stationery Office): Norwich, UK, 2006; ISBN 0-11790-652-2.
67. Ribeiro, I.; Kaufmann, J.; Schmidt, A.; Peças, P.; Henriques, E.; Götze, U. Fostering selection of sustainable manufacturing technologies—A case study involving product design, supply chain and life cycle performance. *J. Clean. Prod.* **2016**, *112*, 3306–3319. [CrossRef]
68. Ciceri, N.D.; Gutowski, T.G.; Garetti, M. A tool to estimate materials and manufacturing energy for a product. In Proceedings of the 2010 IEEE International Symposium on Sustainable Systems and Technology, ISSST 2010, Arlington, VA, USA, 17–19 May 2010.
69. Baumers, M.; Tuck, C.; Hague, R.; Wildman, R.; Ashcroft, I. A comparative study of metallic additive manufacturing power consumption. In Proceedings of the Solid Freeform Fabrication Symposium, Austin, TX, USA, 9–11 August 2010.
70. Ben-Ner, A.; Siemsen, E. Decentralization and Localization of Production. *Calif. Manage. Rev.* **2017**, *59*, 5–23. [CrossRef]
71. Simon, M. When Copyright Can Kill: How 3D Printers Are Breaking the Barriers Between "Intellectual" Property and the Physical World. *Pace Intellect. Prop. Sport. Entertain. Law Forum* **2013**, *3*, 60–97.

72. Airbus, S.A.S. *Aircraft Characteristics Airport and Maintenance Planning (Rev. nº 22)*; Airbus S.A.S: Blagnac, France, 2020.
73. Eurocontrol Experimental Centre. *User Manual for the Base of Aircraft Data (BADA) Revision N 3.9—EEC Technical/Scientific Report No. 11/03/08-08*; Eurocontrol: Les Bordes, France, 2011.
74. Purchasing Power Parities (PPP). OECD Ilibrary. Available online: https://www.oecd-ilibrary.org/finance-and-investment/purchasing-power-parities-ppp/indicator/english_1290ee5a-en (accessed on 1 September 2020).