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A data-based business concept to support product creation in reducing greenhouse gas emissions

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Abstract

The anthropogenic climate change and the resulting global warming cause a multitude of problems for humans and the environment. For this reason, politicians have set ambitious climate targets with the adoption of the Paris Climate Agreement and the implementation of the European Green Deal. However, especially in the industrial sector, the savings of climate-damaging greenhouse gas emissions have so far fallen short of the politically set targets. A significant lever to reduce emissions in production is offered when optimal decisions are already made in the product creation process. One approach is shifting the focus from the product itself to the provision of its service, so different options for geometry, material, manufacturing process and machines are enabled. By forecasting a carbon footprint for each variation of the mentioned options, the greenhouse gas optimal configuration can be identified. Automating this process requires a trustful data and service exchange framework with interfaces, where data exchanges (e.g. raw material properties) and service provisions (e.g. prognosis algorithm for energy consumption) are simplified. Lastly, an inherent changeover and investments must be justifiable in terms of measurable benefits and return on investment for participating companies.

This paper aims to propose a data-driven business model for the greenhouse gas emission reduction in product creation. It addresses the data and revenue streams for the participating stakeholders by a use case from the field of plastic injection molding within the Gaia-X lighthouse project EuProGigant. In this context, the underlying business model architecture is derived. Finally, possible economic potentials and chances for saving greenhouse gas emissions are discussed. Likewise, possible obstacles that could prevent economic operation in industrial practice are also addressed.

Keywords: carbon reduction, data economy, injection molding

1. Introduction

The pressure on manufacturing companies to reduce greenhouse gas emissions continues to increase. It is expressed through ever stricter political regulations and a growing awareness and expectations among customers [1]. For the affected companies in the manufacturing industry, the problem arises of achieving an overall reduction in greenhouse gas emissions to meet these targets in a tension field with economic objectives. In order to operate successfully within this field, it is necessary to identify and address those areas with a high potential for emissions savings [2]. The product creation phase represents the most significant lever for reducing greenhouse gas emissions. In this initial phase, a large part of the inherent greenhouse gas emissions generated during a product's life cycle is determined [3]. Decisive factors in this regard include component design as well as the selection of materials, manufacturing processes, machinery and tools [4]. To date, one problem is that necessary data and tools for greenhouse gas-optimized product design are difficult to access for companies [5].

To solve this, incentives must be created for all relevant stakeholders to engage in a joint exchange. Therefore, the following paper aims to present a data-based business model to support the reduction of greenhouse gas emissions in product creation. First, existing approaches to CO_2-equivalent (CO_2e) reduction are addressed in the related work section. Then, the overarching concept is presented in terms of the players involved as well as its data and revenue streams. Finally, the economic and ecological potential of the concept as well as possible obstacles in the practical implementation will be discussed based on a use case from the plastics processing industry.

2. State of the art

In the wake of the Paris Climate Agreement and the European Green Deal, companies are increasingly forced to make efforts in reducing their CO_2e footprint. A fundamental requirement for this is the ability to record CO_2e emissions of a company's products. Over the course of time, several normative guidelines have emerged for the standardized recording of the CO_2e footprint. DIN EN ISO 14064 [6] provides a framework for balancing greenhouse gas emissions at the organizational level. At the product level, DIN EN ISO 14067 [7] can be used. Both standards are consistent with the international standard for life cycle assessment (ISO 14040 and ISO 14044), which analyses potential environmental harm along the whole life cycle or in defined boundaries (e. g. cradle to gate). Nevertheless, regarding the accounting of indirect greenhouse gases (so-called scope-3 emissions), the standards do not provide any detailed instructions for action. In order to compare information across the product life cycle meaningfully and ultimately use it effectively to save emissions, concrete, industry-specific criteria for CO_2e accounting and a uniform methodology are needed. First steps in this direction are made by companies such as Siemens with its SiGREEN product [8] and SAP with its SAP Product Carbon Footprint Analytics solution [9], who wants to enable CO_2e accounting along the value chain. These software products aim to balance CO_2e emissions for existing products when process flows in production have already been set.

In order to utilize the transparency gained to achieve CO_2e savings, appropriate action measures are required. Within the discrete manufacturing of components, there are various levers for influencing lifecycle CO_2e emissions [10]. Current efforts in industry are mostly limited to the retrospective optimization of already established manufacturing processes for existing products. Corresponding measures include, for example, switching to newer and more energy-efficient machinery or sourcing energy from renewable sources [11]. There are also data-based approaches to CO_2e reduction at the research level. By using data in maintenance, for example, it is possible to extend the useful life of machines and systems and their components. This avoids emissions from the production of unnecessarily installed spare parts and non-optimal use of energy and resources as a result of wear-related degradation [12,13]. In the field of quality management, data-based applications are used for the early detection of production defects. As a result, emissions can be avoided by using energy and resources in the further processing of defective components and the destruction or costly recycling of scrap parts [14,15].

To achieve significant emission savings with an optimal cost-benefit ratio, companies are encouraged to prioritize the largest contributors. According to a recent study by Fuchs et al., "up to four-fifths of a product's lifetime emissions are determined by decisions made at the design stage" [3]. If these potentials are only identified in later phases, their implementation may involve considerable and, in the worst case, unrealizable effort. For this reason, the effects of subsequent phases should be implied as early as possible in the product design phase or as early as possible in the product development process. A clever design can then reduce CO_2e emissions without limiting the actual functionality of the product. Previous efforts in the area of emissions reduction in the product development process involve expert knowledge to a large extent. They therefore require access to relevant data sources and a deep understanding of the underlying technical system [16]. In this context, platform and data-based approaches can realize potential by aggregating and analyzing data from various sources and using domain knowledge. However, there are no known approaches of this kind in the literature yet.

In order to find acceptance and dissemination in industrial practice, such data based approach must be compatible with economic targets. One of the main reasons for a failure of data-based solutions in industrial practice is a lack of business understanding and a lack of testing the economic viability within the development phase [17]. This can be avoided through the development of a sustainable business model that links the technical solution to its economic value. Such a business model consists of the three complementary dimensions of value generation, value proposition and revenue structure [18]. The value proposition dimension represents the benefits that a company provides to its customers with a particular product or service. The value generation dimension captures the required key processes and competencies to fulfill the value proposition. Finally, the revenue structure dimension describes the composition of cost and revenue mechanisms and thus determines the value generated from the business [19]. As already indicated, sustainable business models that aim to reduce CO_2e emissions face particular difficulty in formulating the value proposition. Accordingly, it needs to become clear to an economy-minded customer what monetary savings or gains result from consuming the offer to create sufficient incentives for participation [20].

3. Sustainability Concept for Product Creation

In this section, we propose a possible ecosystem which supports a product creation process in reducing greenhouse gas emissions. To build up such an ecosystem three main factors come into play:

- A common understanding of the carbon footprint calculation method (e.g., ISO 4076 or own methods considering scope-3 emissions as well)
- A secure digital ecosystem, where data and services can be made available, collated and shared in an environment of trust, like the proposals from the Gaia-X framework [21].
- A self-supporting business model to motivate the efforts for participating in the ecosystem.

Figure 1 shows the principle concepts of the data flows within the ecosystem.

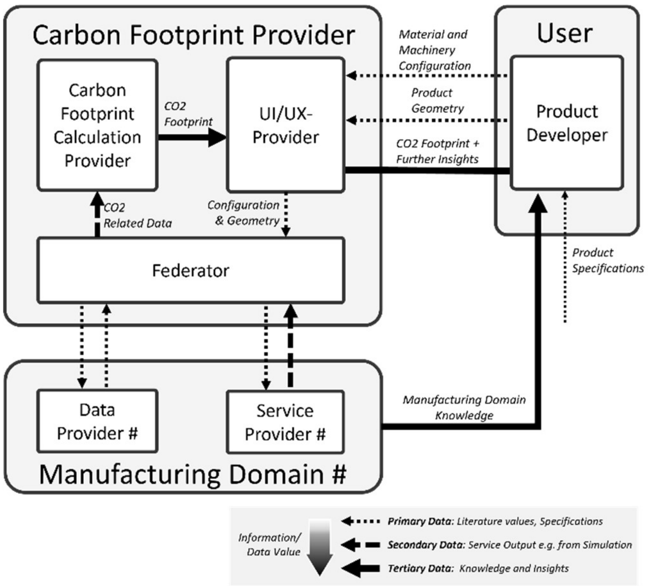

Figure 1: Overview of data streams within the ecosystem

The different participants in the ecosystem can be divided into three main groups. The first group *User* represents product designers aiming to minimize the carbon footprint of a product soon to be developed in order to fulfill internal or external requirements. Prerequisites are some degrees of freedom within the product requirements. The designer's expertise lies within the product construction, but not necessarily in calculating carbon footprints.

To optimize product creation, he therefore needs support from the second group *Carbon Footprint Provider*. Here we define three roles: A user-interface provider, which collects the necessary data from the user (proposed product geometry, material and machinery configuration etc.) and presents the calculated carbon footprint and its analysis to show leverages for CO_2e-reduction. The main role in the ecosystem lies within the federator. To comply with the Gaia-X principle of self sovereignity, we propose its role not as a central data collector but as an orchestrator for data and revenue streams. On a technical level, the federator is responsible, among other things, for secure data transmission, cataloging of offers and identification of subscribers. In the context of Gaia-X, the Federator can use the open source Gaia-X Federation Services to fulfill its activities. In doing so, the Gaia-X Policies & Rules support in ensuring data sovereignty for all parties involved. At the organizational level, the Federator assumes tasks within data space governance. This includes, among other things, the structured integration of relevant stakeholders, the elaboration and further development of the basic organizational and technical requirements, prerequisites, and foundations of the data room, the onboarding of new members, and the strategic linking of the data room with other data rooms [22]. In the context of CO_2e balancing, this also includes ensuring the credibility of exchanged CO_2e data. Currently, companies calculate their carbon footprint on the basis of measurements or, in the case of a lack of data, on the basis of empirical values and assumptions. The respective level of detail and complexity varies. By taking measures to standardize and ensure compliance with these, the federator creates the necessary credibility [23]. For the provision of these services, payments - e.g., in the form of a transaction fee or a subscription - are made by the participants.

The *Manufacturing Domain* represents the third group, delivering the necessary data of the selected machinery and material configuration. Here we distinguish between data providers, delivering values from data bases (e.g. raw material properties) and service providers processing data via (model-based) computations such as simulations and thus generating added value to the input data by transforming it into information. After the carbon footprint for one specific configuration is calculated, the user can start further computations with a different material or machinery configurations and finally select the option with a minimal carbon footprint. Figure 2 shows the possible revenue streams.

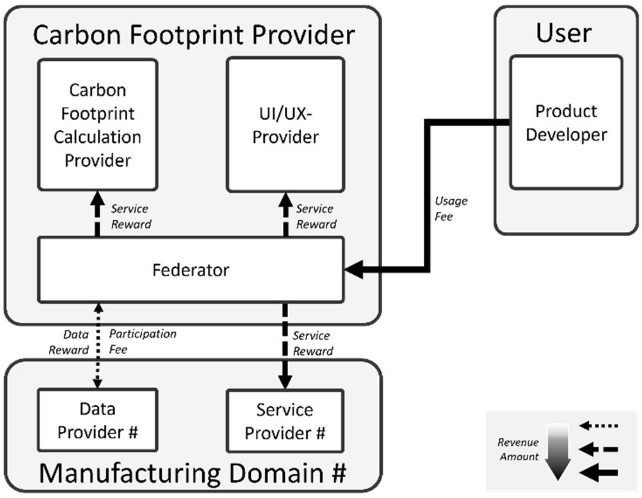

Figure 2: Overview of revenue streams within the ecosystem

While all stakeholders within the ecosystem can use their participation for better public relations, several more different kinds of revenue streams could motivate them to participate. For the user, a prognosis of a disaggregated carbon footprint provides valuable information about the energy consumption and leverages how to minimize it, as well as information about the overall CO_2e-emissions which supports the adaption to external regulations. In many cases, the reduction in emissions is accompanied by a reduction in the use of resources and energy, resulting in further potential savings. Therefore, the user would be willing to pay a usage fee, which is split among the manufacturing domain and the carbon footprint provider. Within the manufacturing domain, the stakeholders are profiting from having their products presented in the configuration options. It offers a competitive advantage since the carbon footprint calculation can be exclusive for them.

Therefore, it is not necessary for the domain stakeholders to have a direct positive revenue stream, also paying a participation fee to the federator would be possible. Further we can distinguish between the concept of only providing (valuable) data with minor processing and having (complex) services delivering computed data. The first party could be satisfied with having no direct revenue streams. If the second party's business model can only depend on the service itself and not necessarily a physical product and it needs a direct revenue stream. Nevertheless, when both parties benefit from the effect on their sales of their products, a participation fee for stakeholders from the manufacturing domain to the carbon footprint provider is also possible.

4. Application

In this section the approach for a sustainable data-based business concept is transferred to the use case “CO_2e footprint in product creation” within the Gaia-X lighthouse project EuProGigant [24]. Therein, the presented concept is applied to the plastic injection molding domain. In this energy-intensive domain, even small efficiency measures offer a high savings potential. The relevance of this topic is evident since the worldwide annual plastics production is 370 million tons [25]. In the considered cluster of stakeholders, the participants currently have no or only partial access to digital tools along the product creation process that enable an early assessment and evaluation of the abovementioned points. For the existing tools there is no interconnection. However, this is necessary to provide a holistic carbon footprint prognosis which supports finding the greenhouse-gas optimal configuration of raw materials, processes and machinery. A working business model is needed to motivate an exchange of data and an extensive data evaluation via computational models within the ecosystem.

The stakeholders in the considered use case are composed as follows: a process simulation provider, a machine manufacturer and a polymer producer. Furthermore, an IoT-platform software company is involved. Some identified leverages are raw material selection, tool construction, type of machine (hydraulic or electric) and right dimension of tool and machine. All configuration options strongly depend on each other, e. g. a different polymer requires a different injection pressure and temperature to form and thus changes in tool or machine are required. In this specific domain neither a central federator nor an adequate data exchange exists, so sub-optimal configurations lead to energy inefficiencies and complex customized machines. Therefore, the working group agreed on building up an ecosystem which should fulfill the following three goals:

- Sensibilization of the designer about his/her influence on the product carbon footprint.
- Quantitative prognosis of a carbon footprint (e.g. for adaption to CO_2e restrictions or estimation of energy costs)
- Assistance for selecting the greenhouse gas optimal machine and raw material configuration.

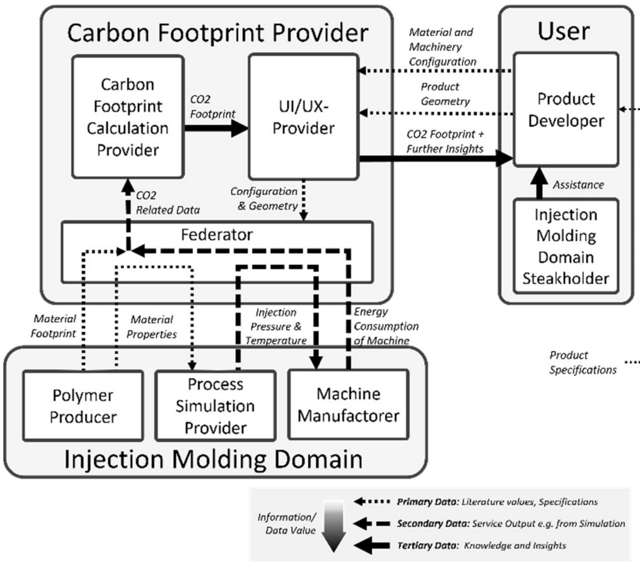

Figure 3: Ecosystem for the plastic manufacturing domain

Therefore, we propose the following model for data streams and service requests and explain the business model (see figure 3). User of the tool is a (potential) customer of one of the injection molding domain stakeholders. His aim is to receive a carbon footprint prognosis. He is thus willing to pay a usage fee. With this stakeholder's assistance the calculation tool would be applied and thus offers an “extra services” which provides a competitive advantage and better custom relations for the manufacturing domain. While all participants have at least partial means and capabilities to calculate part of the carbon footprint, a central orchestration of the data flows (to downstream services) and revenue streams is needed. In the present case, there are different ways to fill the role of the federator. This can be an external third party or one of the stakeholders already named. However, legal obstacles rule out the possibility of the CO_2e calculator simultaneously assuming the role of the federator. This is due to the provisions of the Data Governance Act, which prohibit data brokers from using the brokered data for their own business purposes. This means that the only data analyses that remain possible are those that are useful for data exchange [26].

The development and provision of the user-interface is managed by the IoT-provider, who also assists the federator and carbon footprint calculator setting up the ecosystem's infrastructure and together builds the group of the *carbon footprint provider*. We assume this group as the most cost-intensive which strongly relies on the usage fee. For the calculation of the footprint the orchestration of different services and databases are necessary to receive a valid and complete carbon footprint prognosis. The injection molding machine manufacturer provides as service for calculating the energy consumption of the machine, which depends on the required pressure and temperature. These are values which the process simulation provider can deliver, when having the product geometry and material properties available, which designer and polymer producer can provide. While it is also conceivable that polymer producers and machine manufacturers participate without a direct revenue stream because of having their products presented, the process simulation provider depends on having a payment since complex simulations are still not fully automated.

5. Results and Discussion

In order to determine the economic and ecological potential of the approach presented in the previous chapter, the method was applied to an exemplary product of a participating company. The component under consideration is a retaining clip that is produced in high volumes [27]. For the optimization, the three factors manufacturing process, material and machine technology were taken into account. In the initial state, the component is manufactured on an injection molding machine with hydraulic drive technology and using polyamide plastic. By applying the presented approach, a combination of an electrically driven injection molding machine and a use of polypropylene was identified as optimal and suitable for meeting the required part specifications. Due to, among other things, the higher efficiency of the drive technology and the lower processing temperature of the material, energy savings of approx. 20% can be achieved. Particularly in energy-intensive plastics processing, this leads to considerable cost and thus competitive advantages for the applying company. Significant reductions can also be achieved in terms of greenhouse gas emissions. Accordingly, the value of CO_2e emissions in the optimized solution is approx. 80% lower than in the original state. On the one hand, this is influenced by the lower energy consumption already described and, on the other hand, by the lower inherent CO_2e emissions of the polymer used.

When including a possible pricing of CO_2e emissions in the industrial manufacturing of discrete products, the resulting economic effects of the optimization are even more pronounced. Such a pricing mechanism for the industrial manufacturing of discrete products does not currently exist but is already in place under the European Union Emissions Trading System (EU ETS) for the power generation, iron and steel production sectors, among others [28]. The plan adopted by the European Commission to introduce a digital product passport for the collection of sustainability data along the entire product life cycle could provide the basis for the introduction of a pricing mechanism in discrete manufacturing [29]. Assuming an expected certificate price of 150€/tCO_2e, the certificate costs in the optimized application case are on par with the energy costs incurred for producing a single component [30]. In addition to these savings potentials within manufacturing, new opportunities also arise for user companies on the sales side. As already mentioned in the introduction to this paper, industrial companies are increasingly demanding that their suppliers disclose the CO_2e emissions of their products and comply with limit values [31]. By reducing CO_2e emissions with the approach presented here, these requirements can be met. For the B2C sector, new sales opportunities arise from the designation of the savings achieved in an emissions label [32]. Accordingly, consumers increasingly see the purchase of low-emission products as a contribution to climate protection and prefer corresponding products [33].

However, the mentioned advantages are also countered by obstacles that might impair the sustainable and successful implementation of the business model in practice. Due to the necessity of bringing together different actors to operate the business model, the presented approach represents a multi-sided platform [34]. One of the biggest challenges in introducing such platform-based business models lies in the chicken-and-egg problem. Accordingly, the operator must convince all parties to participate, knowing full well that benefits will be compromised or nullified by the absence of the other parties [35]. A major reason for a lack of participation by manufacturing companies in data-based business models is the unwillingness to share data. Companies are only willing to share their data when end-to-end sovereignty over the use and whereabouts of the data is ensured [36]. This problem is addressed in the EuProGigant context by considering the Gaia-X principles and using its underlying data space concepts (e.g. the sharing of metadata) [37]. Accordingly, all resources, service offerings, and participants in a Gaia-X ecosystem have a self-description. This allows to define with which parties' data is shared and for which service offerings it can be used. Thus the data sovereignty of all participants is protected and ensured [38].

Another hurdle lies on the expenditure side of the business model under consideration. Here, it must be clarified which costs arise for the recording, processing, provision and analysis of the necessary data sets by the players involved. The decisive factor here is whether the benefit generated by the customer exceeds the necessary expenses, thus creating a revenue opportunity for the provider side. From an ecological perspective, the operation of the solution also generates expenses in the form of emissions from the operation of the data infrastructure. These effects have not yet been evaluated. However, it can be assumed that the emissions from non-continuous data acquisition and processing are negligible.

6. Conclusion and Future Research

This paper presents the EuProGigant sustainability approach to support product creation in reducing greenhouse gas emissions. The approach is based on combining the database of different actors within a domain and deriving a CO_2e-optimal configuration through data analysis. To illustrate the approach, the basic architecture of the business model was presented first. It shows all the necessary actors and their relations to each other through data and revenue streams. A practical implementation of the concept was then illustrated using an example of the plastics processing industry. The individual actors and the necessary data sources in the domain in question were identified in this process. Finally, the economic and ecological potentials as well as possible obstacles to the approach in industrial practice were discussed. It can be concluded that significant reductions in energy costs and CO_2e emissions can be achieved for an example component.

Future research efforts should particularly address the identified hurdles in practical implementation in industry. In this regard, it should be considered how the currently evolving Gaia-X mechanisms can be feasibly integrated into the overall architecture. Another important point is to address and integrate the aspect of internal value sharing between the stakeholders on the provider side. Finally, the aim should also be to test the approach in further use cases within the plastics industry as well as other domains. Thus, further transparency about the expected benefits of the solution can be established.

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References

[1] Sikora A.. European Green Deal – legal and financial challenges of the climate change. ERA Forum 2021; 21 (4), p. 681–697.

[2] Pee A, de Pinner D, Roelofsen O, Somers K, Speelman E, Witteveen M. Decarbonization of industrial sectors: the next frontier. New York: McKinsey & Company; 2022.

[3] Fuchs S, Mohr S, Öreback M, Rys J. Back to the drawing board. Operations Practice. New York: McKinsey & Company; 2022.

[4] Kaebernick H, Kara S, Sun M. Sustainable product development and manufacturing by considering environmental requirements. Robotics and Computer-Integrated Manufacturing 2019; 19 (6), p. 461–468.

[5] Despeisse M, Chari A, González Chávez C, Monteiro H, Machado C, Johansson B. A systematic review of empirical studies on green manufacturing: eight propositions and a research framework for digitalized sustainable manufacturing. Production & Manufacturing Research 2022; 10 (1), p. 727–759.

[6] DIN EN ISO 14064-1:2019-06, Treibhausgase_- Teil_1: Spezifikation mit Anleitung zur quantitativen Bestimmung und Berichterstattung von Treibhausgasemissionen und Entzug von Treibhausgasen auf Organisationsebene (ISO_14064-1:2018); Beuth, Berlin.

[7] DIN EN ISO 14067:2019-02, Treibhausgase_- Carbon Footprint von Produkten_- Anforderungen an und Leitlinien für Quantifizierung (ISO_14067:2018); Beuth, Berlin.

[8] Siemens Aktiengesellschaft. Dekarbonisierung beginnt mit Daten: Mit SiGREEN den CO2-Fußabdruck Ihrer Produkte gezielt optimieren. https://www.siemens.com/de/de/unternehmen/themenfelder/product-carbon-footprint.html. Accessed 11 January 2023.

[9] Baur P. Im Kampf gegen den Klimawandel bringt SAP eine neue Lösung für die CO2-Bilanzierung auf den Markt. Walldorf: SAP; 2022.

[10] Su J, Chu C, Wang Y. A decision support system to estimate the carbon emission and cost of product designs. IJPEM 2012; 13 (7), p. 1037–1045.

[11] Panagiotopoulou V, Stavropoulos P, Chryssolouris G, 2022. A critical review on the environmental impact of manufacturing: a holistic perspective. IJAMT 2022; 118 (1-2), p. 603–625.

[12] Brockhaus B, Hoffmann F, Metternich J, Weigold M. Predictive Maintenance for Flexible Protective Covers in Machine Tools, in: Behrens B, Brosius A, Drossel W, Hintze W, Ihlenfeldt S, Nyhuis P, editors, Production at the Leading Edge of Technology. Cham: Springer; 2022. p. 177–185.

[13] Cheng Y, Zhu H, Wu J, Shao X, 2019. Machine Health Monitoring Using Adaptive Kernel Spectral Clustering and Deep Long Short-Term Memory Recurrent Neural Networks. IEEE TII 2019; 15 (2), p. 987–997.

[14] Lee S, Tama B, Moon S, Lee S. Steel Surface Defect Diagnostics Using Deep Convolutional Neural Network and Class Activation Map. Applied Sciences 2019; 9 (24), p. 5449.

[15] Susto G, Beghi A, McLoone S. Anomaly detection through on-line isolation Forest: An application to plasma etching, in: 2017 28th ASMC. Saratoga Springs, NY, USA. 15.-18.05.2017. IEEE 2017, p. 89–94.

[16] Leisinger D, Heinrich A, Hübner D, Albers T. Carbon reduction by design: How to shrink your product portfolio's CO2e footprint. Industrial Goods and Services. Chicago: Kearney; 2022.

[17] Ermakova, T, Blume J, Fabian B, Fomenko E, Berlin M, Hauswirth M. Beyond the Hype: Why Do Data-Driven Projects Fail?, in: Proceedings of the 54th Hawaii ICSS; 2021.

[18] Gassmann O, Frankenberger K, Choudury M. The business model navigator: 55 models that will revolutionise your business. München: Pearson; 2014.

[19] Chesbrough H. Business model innovation: it's not just about technology anymore. Strategy & Leadership 2007; 35 (6), p. 12–17.

[20] Seidel J, Barquet A, Seliger G, Kohl H. Future of Business Models in Manufacturing, in: Stark R, Seliger G, Bonvoisin J, editors. Sustainable Manufacturing. Cham: Springer; 2017. p. 149–162.

[21] Hoffmann F, Weber M, Weigold M, Metternich J. Developing GAIA-X Business Models for Production. Hannover: publish-Ing; 2022.

[22] Gaia-X AISBL. Gaia-X Architecture Document. Brussels: Gaia-X; 2022. https://www.gaiax.es/sites/default/files/2022-01/Gaia-X_Architecture_Document_2112.pdf. Accessed 27 January 2023.

[23] Catena-X Automotive Network e.V.. Standards and methods for saving carbon dioxide. Berlin: Catena-X; 2023 https://catena-x.net/en/mehrwerte/sustainability. Accessed 27 January 2023.

[24] Weber M, Weigold M, Koch T, 2022. The European Production Giganet: Towards a Green and Digital Manufacturing Ecosystem, in: Smart and Networked Manufacturing. WPK, Wien. 05.-06.10.2022. Wien: new academic press; 2022., p. 95–100.

[25] Reckter B, 2022. Vom Kunststoff zum Rohstoff. Düsseldorf: vdi; 2022.

[26] Ditfurth L, Lienemann G. The Data Governance Act: Promoting or Restricting Data Intermediaries? Competition and Regulation in Network Industries 2022; 23 (4), p. 270–295.

[27] Hoffmann F, Koch T, Weigold M, Metternich J, 2023. Development Of Data-based Business ModelsTo Incentivise Sustainability In Industrial Production. Hannover: publish-Ing; 2023.

[28] Frankovic I. The Impact of Carbon Pricing in a Multi-Region Production Network Model and an Application to Climate Scenarios. SSRN Journal 2022.

[29] European Commission. Green Deal: New proposals to make sustainable products the norm and boost Europe's resource independence. Brussels: European Commission; 2022.

[30] Steele L, Fisher A, Gleeson A, Ip Tat Kuen M. Raising power prices by 50%: carbon to EUR150/t. Utilities. Hamburg: Berenberg Bank; 2022.

[31] Deloitte. Sustainable manufacturing: From vision to action. London: Deloitte; 2021. https://www2.deloitte.com/content/dam/Deloitte/ch/Documents/manufacturing/deloitte-ch-en-sustainable-manufacturing-2021.pdf. Accessed 23 January 2023.

[32] Taufique K, Nielsen K, Dietz T, Shwom R, Stern P, Vandenbergh, M. Revisiting the promise of carbon labelling. NCC 2022; 12 (2), p. 132–140.

[33] Feucht Y, Zander K. Consumers' attitudes on carbon footprint labelling: Results of the SUSDIET project. Thünen Working Paper 78. Braunschweig: Thünen-Institut; 2017.

[34] Parker G, van Alstyne M, Choudary S. Platform revolution: how networked markets are transforming the economy - and how to make them work for you. New York: W.W. Norton & Company; 2016.

[35] Trabucchi D. Let's Get a Two-Sided Platform Started. Journal of Business Ecosystems 2022; 1 (1), p. 63–77.

[36] Otto B, Mohr N, Roggendorf M, Guggenberger T. Data sharing in industrial ecosystems: Driving value across entire production lines. Berlin: McKinsey & Company; 2020.

[37] Dumss S, Weber M, Schwaiger C, Sulz C, Rosenberger P, Bleicher F, Grafinger M, Weigold M. EuProGigant – A Concept Towards an Industrial System Architecture for Data-Driven Production Systems. Procedia CIRP 2021; 104, p. 324–329.

[38]Gaia-X AISBL. Self-Description of Resources, Self-Description of Resources, Service Offerings and Participants within Gaia-X Ecosystems: Decentralised, cryptographically secure, interoperable, extendible, and future proof. Brussels: Gaia-X AISBL; 2022.