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# Technology Valuation Method for Supporting Knowledge Management in Technology Decisions to Gain Sustainability

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**Abstract:** New technologies have major effects on the profitability of companies and the economic growth of society. If appropriate technologies can be routinely selected, then it is possible to achieve sustainability at a company level. Knowledge management (KM) can be used to support technology decision making and give an understanding of the potential of particular technologies in a specific business environment. In this study, the design research methodology (DRM) is used with three case studies in an industry environment to develop and evaluate a novel technology valuation method (TVM). The proposed six-step TVM focuses on the acquisition, modeling, and validation of product-related knowledge to support KM related to technology decisions. The contribution of this research is to use distinctions between product properties and behaviors with a disposition toward understanding the potential of technology. During the process, tacit knowledge is made visible and documented, which supports the reliability of technology decisions and enables companies to gain sustainability.

**Keywords:** technology; technology decision; knowledge management; manufacturing industry; technology valuation; sustainability

## 1. Introduction

All companies pursue economic sustainability. Sustainability has three overlapping components: economy, society, and environment [1]. The economic aspects are the focus of this research. Economic sustainability refers to “the capacity of the firm to be profitable not only today but also tomorrow” [2]. Environmental sustainability focuses on upholding the ecosystems that provide the resources and services needed by current and future generations [3], while social sustainability concentrates on communities and the processes associated with creating healthy communities [4]. The aim of this paper is to propose a novel technology valuation method (TVM) to support knowledge management (KM) in technology decision making in the manufacturing industry to gain sustainability.

Technology influences the profitability of companies and the economic growth of society [5,6]. This emphasizes the need for the successful management of technology. The main aims of KM are to create value for customers and to gain competitive advantages [7]. This paper focuses on the acquisition and use of knowledge related to technologies to evaluate the potential of a particular technology from the perspective of the company that is acquiring it. Technology valuation refers to the direct output of valuation methods (i.e., an evaluation of the potential of a technology), while the pricing of technology involves determining the price of acquiring the technology [8]. Technology valuation is one element of the technology decision-making process, which includes five steps: defining the alternatives,

identifying the alternatives, determining the criteria, evaluating the alternatives, and choosing the best alternative. This process can also apply to technology decisions [9]. Technology valuation supports the steps of determining the criteria to be used to evaluate the alternatives, then evaluating the alternatives. Ilori and Irefin [9] describe various approaches to decision making; the current research uses a rational analytic approach, which is suitable for problems that are complex and important, as in the case of technology decisions.

Generally, three asset valuation approaches are recognized: cost, market, and income [10]. The income approach is the most frequently recommended [10–12] in technology valuation. The income approach considers the future earning potential of a technology based on expected future benefits [10]. To evaluate the future benefits, several methods have been proposed; however, the reliability of the knowledge used by these methods and the reasoning behind the knowledge have not been adequately explained. Most of these methods assume that expert knowledge is reliable. Chiesa et al. [13] state that the “limitation of monetary methods descends from their quantitative nature . . . despite the objectivity of the procedure’s results, they suffer from the assumptions made during the estimation of the parameters.” According to Dissel et al. [14], many decisions are still made on the basis of expert judgment and gut feelings. Dissel et al. [14] highlight the motivation of this research, concluding that “further work is needed to understand how best to integrate the outputs into the broader technology investment processes in the firm.” Our motivation is to use and implement theories from engineering design research in technology valuation to improve the valuation reliability. We are attempting to model the interplay between technology, products, and their lifecycles, and to validate the model within the TVM. This is achieved by making assumptions about the dependencies between product properties and the behaviors of products during their lifecycles.

Based on the above-mentioned references [10,11,14], the research gap is that technology valuations are mostly based on assumptions. The aim is to improve the reliability of the knowledge used in valuation and to ensure that the reasoning behind a technology decision is visible and evaluable. To address the knowledge-related gap in technology decisions, the proposed TVM focuses on product and design knowledge, since technology affects through products [15], and products affect business and sustainability [16–19]. The knowledge regarding the relationship between product properties and behavior is key to the proposed TVM. In order to describe the required knowledge, acquire this knowledge from individuals and organizations, and use this knowledge to support technology decisions, the following research questions (RQ) were set:

**RQ1:** What is the key individual and organizational knowledge needed in technology valuation to make the assumptions visible in order to support sustainability?

**RQ2:** How can the key individual and organizational knowledge be acquired?

**RQ3:** How can this key individual and organizational knowledge be used in decision making?

These questions were answered using the design research methodology (DRM) [20] and three case studies [21] that were conducted in the real industry environment of an original equipment manufacturer (OEM) in a mining business. Our aim was to research the acquisition and use of knowledge related to technologies in the manufacturing industry. To choose the case company, we had three criteria: (1) all critical knowledge had to be available; (2) researchers required access to the data; and (3) we would be granted permission to publish the results. The selected case company fulfilled all the criteria and was chosen in order to facilitate a successful research project.

The main contribution of this research is to focus on products and especially on the distinctions between product properties and behavior in KM in technology valuation and decision making. A practical TVM is proposed, which constitutes the main managerial contribution of this research. By using the TVM, it is possible to improve the reliability of technology valuation and thus make sustainable technology decisions. The proposed TVM is based on understanding the product properties and behavior to describe their dispositions. Therefore, if the products and technologies being evaluated

do not have these dispositions, or if the required knowledge is not available, this method cannot be used.

The structure of this paper is as follows: The introduction is given in Section 1, followed by the literature review discussing KM and engineering design research (EDR) in Section 2. A scientific approach is discussed in Section 3, the results of the research in the form of proposed TVM are given in Section 4, and a general discussion and conclusion are in Section 5.

## 2. Literature Review

In this section, theories regarding KM and EDR are discussed from the perspective of supporting technology decision making. Our aim is to develop and propose a practical method. Newell [22] describes the method with four statements: it is a specific way to proceed, it is a rational way to proceed, it involves subgoals and subplans, and its occurrence is observable. These statements guide the development of the proposed TVM, and the fulfillment of the criteria are evaluated in the discussion in Section 5.

### 2.1. Knowledge Management (KM)

Lloria [7] has done a comprehensive review of the main approaches to knowledge management, and based on that review, KM is a broad concept that includes the following aspects:

1. It “is related both to business practice and to research”. The authors researching KM come from various disciplines, providing important insights, but on their own no individual author provides an integrating framework.
2. It “goes further than technology management or information management”. Tacit knowledge, human intervention, and learning are the key aspects, rather than information technology.
3. It “is a broad concept, and is made up of different activities”, including, among other things, the creation and application of knowledge.
4. It “is principally found in people and is developed through learning”. Knowledge should evolve from a human asset to a business asset.
5. Developing new opportunities, creating value, or obtaining a competitive advantage are possible aims for KM.

Research on organizational learning and KM can be described as levels of KM outcomes (creation, retention, and transfer) and KM context (properties of units, properties of the relationships between units, and properties of knowledge) [23]. A three-dimensional model for describing the framework of KM was presented by Choo and Neto [24], who added the enabling condition level to the aforementioned outcomes and context. The influence of knowledge, innovation, and technology management capabilities on research and development are examined by Asim and Sorooshian [25], and three types of capabilities are highlighted: process, infrastructure, and strategic. This paper focuses on all three of these outcomes, and in the context of KM, the levels of units (individual and organizational) and knowledge are put under analysis. Argote, McEvily, and Reagans [23] emphasize the role of social relations and human factors in managing knowledge.

Different countries and regions have taken divergent directions regarding the development of KM. European companies focus on measuring knowledge, while American companies are concerned with management, and Japanese companies are approaching the task by creating new organizational knowledge. The origins of these differences in perspectives are, for example, how knowledge is understood, what the company does with the knowledge, and who the key individuals are [26].

Earl [27] considered KM strategies and schools in order to propose a taxonomy, and he identified several categories or schools. This present paper uses the systems-based technocratic school and the spatial-based behavioral school. The technocratic school is based on management technologies that support employees’ everyday tasks. The fundamental idea behind this systems-based school is to capture specialist knowledge, which other specialists can then access. This is a means of capturing

individual or group knowledge and sharing it for organizational use. The behavioral school is based on stimulating and orchestrating managers for effective KM. This spatial-based school concentrates on the use of space to facilitate the exchange of knowledge. The Japanese concept of “ba” is discussed in [28] as a fundamental condition for knowledge creation and KM, and it can be understood as having a similar ideology as the spatial school.

As described above, knowledge acquisition is an important aspect of KM. However, the knowledge transfer among individuals in a group must also be taken into account. Alavi and Leidner [29] present modes of knowledge creation between individuals that range from tacit to explicit. At the level of the individual, after the application of knowledge, it is possible to learn (i.e., increase) tacit knowledge. After this tacit knowledge is explicitly implemented (modeling and documenting), it is possible to transfer the knowledge to the group’s semantic memory and vice versa. The transfer of individual tacit knowledge directly to the group’s episodic memory is also possible [29]. Additionally, trust in management has positive effects on employee creativity toward achieving sustainability [30], which can be supported by knowledge transfers.

The above references are used to answer RQ2 and RQ3, regarding how knowledge is acquired and how it can be used. The proposed TVM strongly relies on the facilitation of knowledge acquisition.

## 2.2. Engineering Design Research (EDR)

In this subsection, theories from EDR that help to fill the gap in the literature regarding the reliability of knowledge are discussed. The aim is to show why product-related knowledge is important and should be efficiently managed if sustainability is to be achieved.

According to Hubka and Eder [31], “The term Design Science is to be understood as a system of logically related knowledge, which should contain and organize the complete knowledge about and for design.” The theory of technical systems (TTS) [15] instead focuses on describing and substantiating technical systems (i.e., products), and TTS are one part of design science. The transformation system includes the main elements of TTS: inter alia, technical systems, technologies, and the transformation process. The need for transformation emerges when the current state is insufficient and the current state of the operand (Od1) must be transformed to the desired state (Od2). In practice, when the energy of fuel (Od1) is transformed to rotational energy (Od2) using a combustion engine, this transformation exists. TTS describes the nature and origin of products, which can be used to represent and understand technical systems.

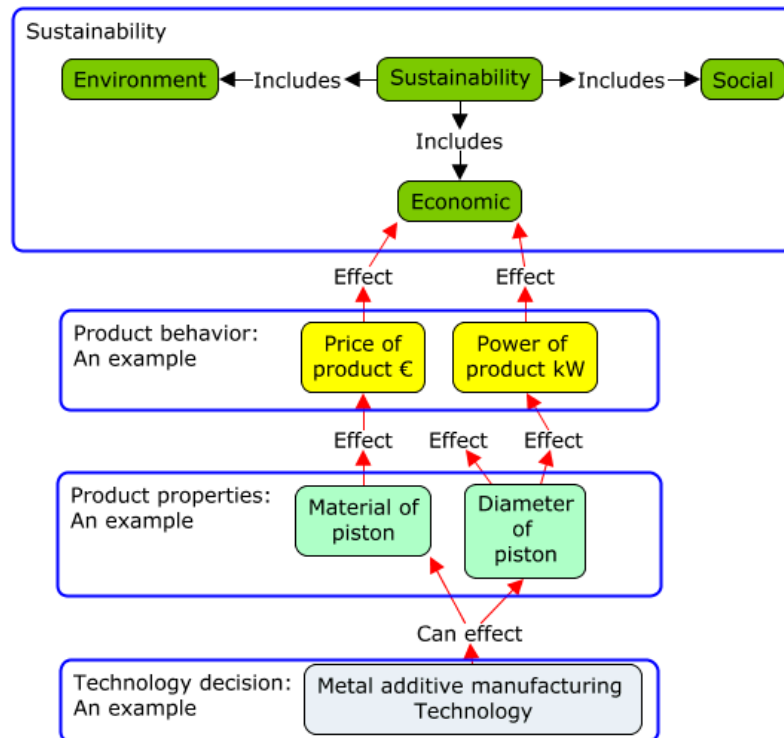
To understand the effects of decisions made in the manufacturing industry, Olesen [19] presented the concept of disposition. Disposition is defined in the following way [19]: “By a disposition we understand that part of a decision taken within one functional area which affects the type, content, efficiency or progress of activities within other functional areas.” This concept asserts an understanding of the lifecycle phases of a technical system, since the product may influence all of the systems that it is subject to. In this paper, the term disposition is used to refer to the link between a decision being made—a technology decision, in this case—and the effects of the technology.

The concept of a disposition that is being presented is still highly theoretical, and more concrete tools are needed to support practical decision making. Two main activities during design are analysis and synthesis. Analysis signifies the process of determining a product’s behavior from its known properties. Synthesis is the opposite process, whereby the product’s properties are defined from a known or given behavior. In this context, product behavior is understood as, for example, the weight or price of a product, and its properties, such as wall thickness and material, can be directly influenced by the designer.

By combining previously mentioned theories and approaches, Andreasen [16] proposed that a product can be described using different domains, such as activity, organ, and part. In each domain, it is possible to use synthesis to reason backwards from behavior to structure. Similar models were developed by Gero [17] and by Weber and Deubel [18] in their property-driven development/design (PDD) theory. PDD focuses on the distinctions between product properties and behavior when

developing and evaluating technical systems. In this research and in the proposed TVM, the PDD approach is used to describe the links between product properties and behavior.

Figure 1 presents the idea of using theories from EDR to support KM for sustainability. At the top of the figure, the economic aspects of sustainability are set as targets. Using PDD, it is possible to use synthesis and determine the desired behavior of a product and further the properties of the product that cause this behavior. Technology can only effect product properties, as demonstrated at the bottom of Figure 1. The dispositions are presented in the figure, using red arrows. The proposed TVM is constructed using the approach being presented. The texts of the smaller boxes in Figure 1 are derived from Case Study 1, which describes the kinds of matters that can be dealt with in each entity.



**Figure 1.** An example of the dispositions between technology decisions and the economic perspective of sustainability, based on engineering design research (EDR) theories.

Because the focus is on knowledge, the following eight key elements are needed to evaluate the potential of a technology [32]. All these key elements are based on EDR theories and are used as the basis for the proposed TVM:

1. Technical system intention and business intention
2. Product lifecycle phases
3. Desired behaviors from lifecycle phases
4. Product structure
5. Technology properties
6. Dispositions between product properties and desired behaviors
7. Potential effects of technology related to the product
8. Estimation of financial numbers related to the product

### 3. Materials and Methods

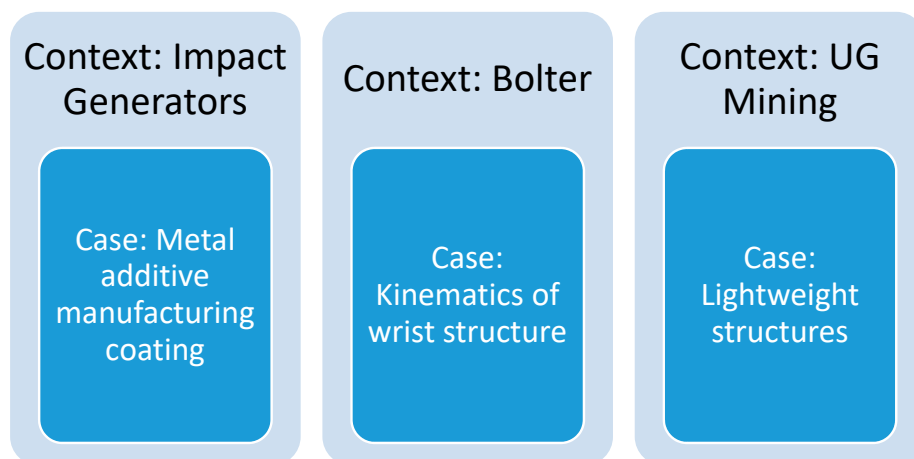
We have chosen to use qualitative research with a constructive approach, due to the nature of the phenomenon being investigated. Our aim is to visually model the assumptions of people, which is the

best available knowledge in the early phase of technology evaluation. In this research, the DRM [20] is used to develop a method to support technology decision making in the manufacturing industry. DRM is a qualitative research method. Table 1 summarizes the research project (Type 3 [20]) according to the DRM and the research phases. The first phase of the DRM is research clarification (RC), which is based on a literature review and focuses on identifying the current research gaps and goals, including the RQs and the relevant disciplines (see Sections 1 and 2). The second phase is Descriptive Study 1 (DS-1), which improves our understanding of the selected research area and is also based on a literature review (Section 2). The prescriptive study (PS) focuses on developing the support needed to improve the current state. In this case, support refers to the proposed TVM, which aims to improve the reliability of the technology-related decisions; this is discussed in more detail in Section 4. Descriptive Study 2 (DS-2) is used for the evaluation and development of the TVM. RQ1 is answered based on the literature reviews of phases RC and DS-1. RQ2 and RQ3 include specific literature reviews, although the main focus is on the development of the TVM and its evaluation using the case studies in the PS and DS-2 phases.

**Table 1.** Steps of the research method, project type, and answers to the research questions (RQ1–3), according to the design research methodology (DRM) [20].

Stage	Research Clarification	Descriptive Study 1	Prescriptive Study	Descriptive Study 2
RQ1	x	x		
RQ2		x	x	x
RQ3		x	x	x
Type 3	Review-based	Review-based	Comprehensive	Initial
Main outcomes	Goals	Understanding	Support	Evaluation

The evaluation and development of the proposed TVM has been conducted using three case studies that employ a holistic multiple-case design (see Figure 2) [21]. Each case study has a different context, meaning different people involved, products researched, and targets.



**Figure 2.** Multiple-case design used in case studies, adapted from [21].

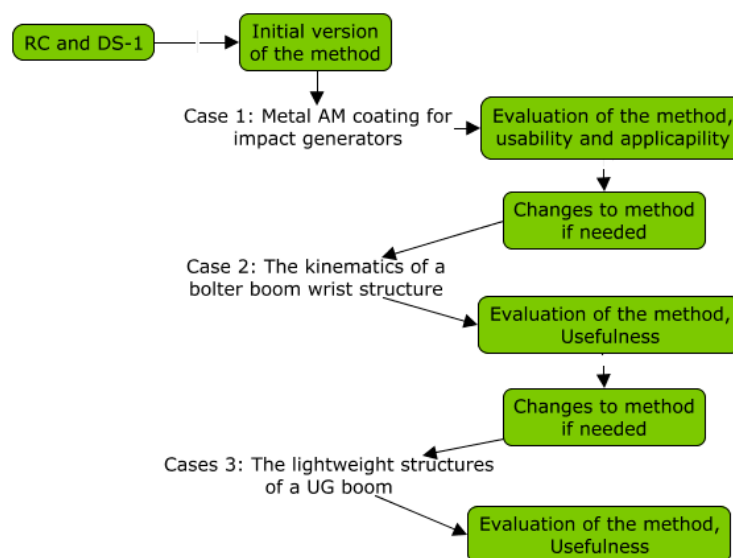
The case studies were undertaken at an OEM in a mining business during 2017 and 2018. To choose our case company, we had three criteria: (1) all critical knowledge had to be available; (2) researchers required access to the data; and (3) we would be granted permission to publish the results. The selected case company fulfilled all the criteria and was chosen. Different technologies and business areas were selected to evaluate and test the proposed TVM, as shown in Table 2. The workload of each step of the proposed TVM is described in Table 2 to show the role of workshops in the proposed TVM. Each step of the TVM includes several workshops to acquire and model the required knowledge.



**Table 2.** Case studies undertaken during the research, evaluation, and development of the technology valuation method (TVM).

	<b>A Metal Additive Manufacturing (AM) Coating for Impact Generators</b>	<b>The Kinematics of a Bolter Boom Wrist Structure</b>	<b>The Lightweight Structures of an Underground (UG) Boom</b>
Case study Technology	Case Study 1 Metal AM coating	Case Study 2 Wrist structure concepts	Case Study 3 Lightweight solutions
Evaluation focus of the TVM according to the DRM	Usability and applicability	Usefulness	Usefulness
Data collection time period	6/2017–2/2018	4/2018–11/2018	4/2018–12/2018
OEM representatives involved	Technology manager Designers (3) Manufacturing manager Manufacturing designer Technology expert (outside the organization)	Product managers (2) Design managers (3) Sourcing manager Technology manager Aftermarket specialist Designers (3)	Technology manager Product managers (2) Designers (3) Design manager
Total workload	98.5 work hours in 27 meetings with 7 different people	93 work hours in 15 meetings with 11 different people	56 work hours in 11 meetings with 7 different people
Step 1: Preliminary targets	Included in step 2 in this case study	2 workshops with 2 different people	1 workshop with 1 person
Step 2: Targets from a business environment	2 workshops with 2 different people	1 workshop with 8 different people	1 workshop with 8 different people
Step 3: Modeling dispositions	22 workshops with 3 different people	8 workshops with 3 different people	8 workshops with 5 different people
Step 4: Evaluation of the exploitation of technology	2 workshops with 4 different people	3 workshops with 2 different people	1 workshop with 4 different people
Step 5: Business impact	1 workshop with 2 different people	1 workshop with 1 person	This was not done in this case study
Step 6: Communicating the value of technology	Included in step 5 in this case study	By the facilitator	By the facilitator

Figure 3 presents the TVM evaluation and development procedure, including the case studies. The initial version of the TVM was developed in the RC and DS-1 phases, and was tested and evaluated in Case Study 1. After each case study, the TVM was evaluated and improved, if needed, and this was done three times after each case study. The proposed TVM is presented in Section 4.



**Figure 3.** The TVM development and evaluation in each case study.

### 4. Results

A complete description of the proposed TVM is presented in Figure 4. The central column shows the method’s steps in the recommended order of business, from top to bottom. On the left are the tools related to each step, mainly workshops with specific tools for acquiring the required knowledge. The outputs of each step and the inputs for the next steps are described on the right side and focus on the use of knowledge.



**Figure 4.** A description of the proposed technology valuation method (TVM), with the knowledge-gathering tools that are used and the outputs that document this knowledge.

Previous studies related to method and its development were undertaken, and the information needed to evaluate the value and cost of technology in the manufacturing industry was discussed in [32]. A method was formulated to acquire the eight key elements found in the previously mentioned research. The first version of this method was presented in [33] and included five steps. The difference between the first version of the TVM and the version proposed in this paper is the addition of the sixth step at the end. It is essential to communicate the value of technology in the form of a final report, where the acquired knowledge is documented and reusable. The following Sections 4.1–4.6 include a detailed description of the steps of the proposed TVM.

#### 4.1. Preliminary Targets and Limitations for Technology Valuation

The purpose of this step is to discuss the preliminary targets and limitations for technology valuation in order to start the valuation process. The first step is conducted in a workshop where the responsibilities of technology decisions in the company are involved. This step focuses on exploring the acquisition of preliminary knowledge for businesses, products, technologies, and organizations and supports the formation of a common understanding among managers regarding the targets of technology. It also helps with the execution of the next step and the participant selection. The contribution of the first step to KM is presented in Table 3, where the knowledge type, key knowledge, acquisition of knowledge, and use of knowledge are shown.

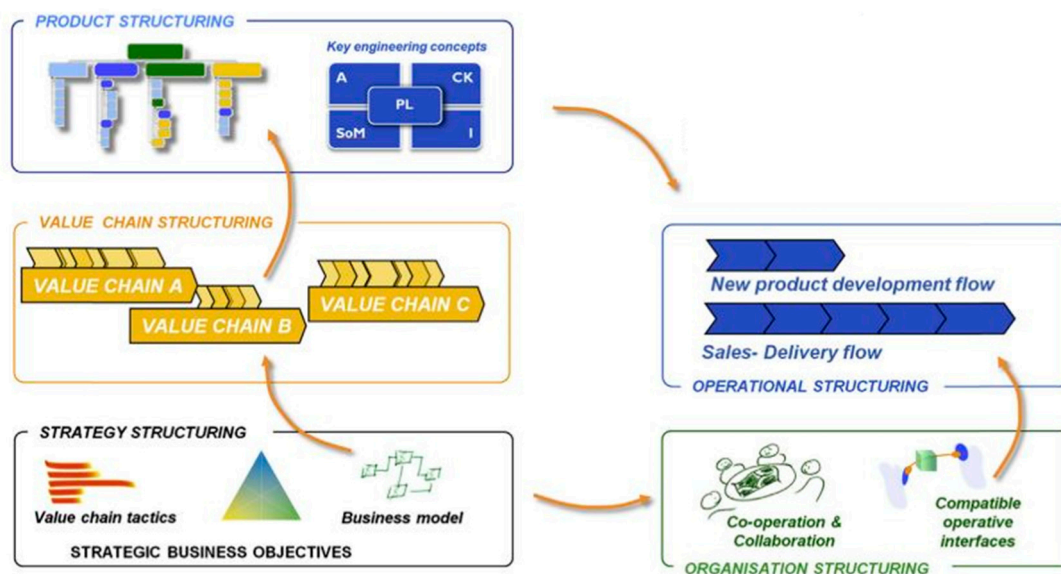


**Table 3.** Contributions of step one of knowledge management (KM) for sustainability.

Knowledge Type	Key Knowledge	Acquiring the Knowledge	Using the Knowledge
Key individual knowledge	Intention of business Intention of product Organization being studied Technology properties	From manager(s) in target setting workshop	To form a shared understanding about the targets
Key organizational knowledge	Intention of business Intention of product Organization being studied	From manager(s) in target setting workshop	Selecting the relevant participants for the second step

4.2. Targets from the Business Environment—The Reasoning Evaluation Criteria

The second step of the proposed TVM focuses on acquiring the targets from the business environment and includes the goals for sustainability. The target setting step contributes to the decision-making process [9] by determining and reasoning the evaluation criteria. The targets are acquired in a company strategic landscape (CSL) workshop with management, as defined in step one. This CSL tool describes five vital elements of the business environment: strategy, value chains, products, processes, and the organization of a company (see Figure 5) [34,35]. Understanding the previously mentioned aspects is also seen as beneficial in the valuation of strategic production decisions [36].



**Figure 5.** The company strategic landscape (CSL) tool, adapted from [35].

Knowledge acquisition begins with the strategy structure box shown in Figure 5, where the scope of the analysis is defined. The results of the first step provide a suitable base for the workshop, with the businesses, products, and organizations defined and available for discussion. The product or business owner generally has the best available knowledge regarding strategy. After the strategic and organizational goals are defined, the process of creating the product is discussed. This area of the CSL tool includes the lifecycle steps of the product in calendar order, including, for example, market research, product development, sales, and recycling.

Knowledge related to product structuring is shown at the top left side of Figure 5. Here, the aim is to split the product into suitably sized entities for evaluation purposes. Generally, the design manager can describe the product structuring used for design purposes, which can also be used in this analysis. Finally, value chains, the most interesting element of the technology valuation context, are discussed and documented within the CSL tool. A value chain is a desired behavior from the product’s lifecycle phases; for example, the price or power of the product. Defining desired behaviors requires extremely

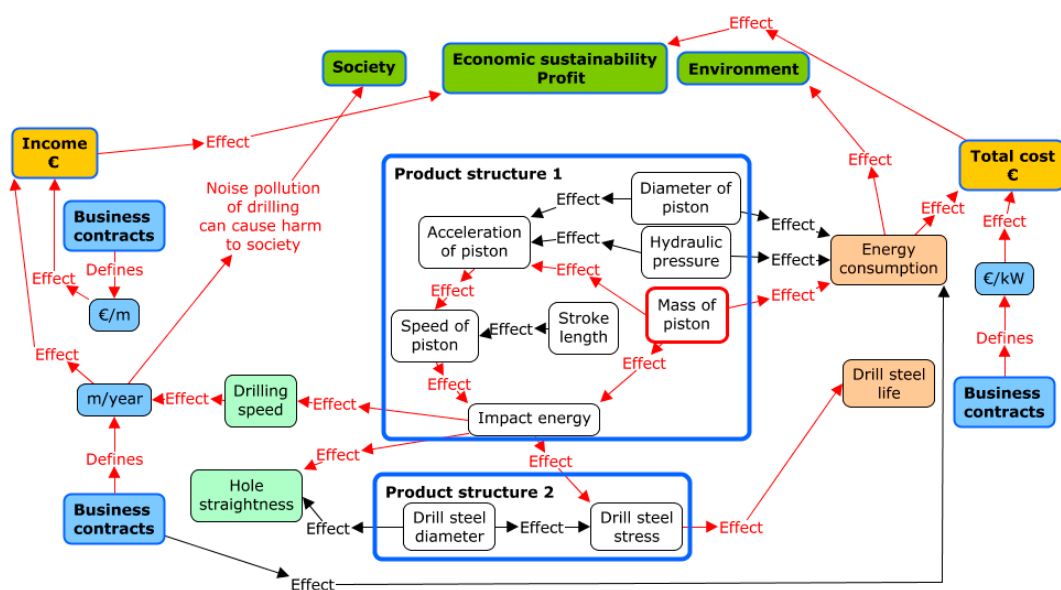
specific knowledge related to the business environment. To form the value chains that were previously described, the product lifecycle phases can be used to support this phase. The owner of a specific product lifecycle phase can be asked “what creates value in your area?” For example, a sales manager may be more focused on the power of a product rather than the price of its parts (the focus of the purchase manager). The contribution of the second step of KM is presented in Table 4. The main focus of the second step is to achieve a common understanding of targets that are related to technology valuation. In the next step, the design knowledge is linked to the targets.

**Table 4.** Contribution of step two to knowledge management (KM) for sustainability.

Knowledge Type	Key Knowledge	Acquiring the Knowledge	Using the Knowledge
Key individual knowledge	Product lifecycle phases Desired behavior from lifecycle phases Product structure	From manager(s) in the CSL workshop using the CSL tool	To form a shared understanding of the targets
Key organizational knowledge	Shared understanding and common agreement of the priority of targets	From manager(s) in the CSL workshop using the CSL tool	Supporting the third step by providing the product structure and the desired behavior of the product

4.3. Modeling Dispositions—Design Reasoning Pattern (DRP)

In this phase, the targets from the business environment are set. In step three, the knowledge of the product and its design is used to communicate how the product fulfills its stated goals. Figure 6 shows the simplified design reasoning pattern (DRP) [37] chart from Case Study 1. The boxes at the top of Figure 6 show the final goals of the technology from the perspective of sustainability (safety, profit, and environment, in this example), which were defined in steps one and two of the TVM. On the left are the desired behaviors of the product (drilling speed and hole straightness) and the reasoning for how these behaviors generate income. On the right are the behaviors that generate costs (energy consumption and drill steel life), with the cost reasoning imported from the CSL tool. In the middle of Figure 6, in the large box with the blue outline, are the product structures, which were also defined in the CSL step.



**Figure 6.** Simplified design reasoning pattern (DRP) example from Case Study 1.

The modeling of the design knowledge, including the distinction of product properties (the boxes in the product structure area) and the desired behaviors, is done with the most experienced designers in the area. The main focus is on understanding how specific properties cause the desired behavior and visualize the links and dispositions between them. It is recommended that several designers should be used when forming the DRP to ensure a comprehensive understanding of the knowledge used in the design. Table 5 shows the contributions of step three to KM.

**Table 5.** Contributions of step three to knowledge management (KM) for sustainability.

Knowledge Type	Key Knowledge	Acquiring the Knowledge	Using the Knowledge
Key individual knowledge	Dispositions between product properties and desired behaviors	From designer(s) in DRP workshops	To form a shared understanding about dispositions
Key organizational knowledge	Shared understanding and common agreements regarding the priority of dispositions	From designer(s) in DRP workshops	To evaluate the potential of technology in step four

#### 4.4. Evaluation of the Exploitation of Technology

In step four of the proposed TVM, the potential of technology is explored, based on the acquired and modeled knowledge on the product and business environment. This is done in two phases—first, with designers, and second, with technology experts, if they are available. Here, the modeled DRP chart is used to support the evaluation. For example, in Case Study 1, the company was eager to find out the benefits of additive manufacturing technology in pulse generators. The current manufacturing technology is based on casting, thermal treatment, and machining. This leads to the technology valuation question formulated as follows: “What are the potential benefits of metal additive manufacturing in pulse generators?” The DRP chart was used to analyze the potential impact. Additive manufacturing potentially enables change in the mass of the piston. This change (see the “Product structure 1” box in Figure 6) has an effect on profit, according to the red arrows in the DRP. The red arrows are understood as dispositions, and the acquired knowledge is used to visualize the potential impact of technology. This step only shows the effects, while the magnitudes of the physical values and the monetary estimations are considered in the next step. The contribution of step four to KM is presented in Table 6.

**Table 6.** The contribution of step four to knowledge management (KM) for sustainability.

Knowledge Type	Key Knowledge	Acquiring the Knowledge	Using the Knowledge
Key individual knowledge	Properties of technology Potential effects of technology according to the modeled DRP	From designer(s) and technology expert(s) in the workshop	To form a shared understanding of the potential of technology
Key organizational knowledge	Shared understanding and common agreement on the potential of technology	From designer(s) and technology expert(s) in the workshop	To evaluate the monetary effects of technology

#### 4.5. Business Impact Analysis (BIA)

The business impact analysis (BIA) is conducted in step five, where the potential of technology is evaluated from an economic perspective. The basis of the evaluation is formulated in the previous

phases (i.e., where knowledge of the potential of technology is acquired, modeled, and validated). The recognized dispositions are valued in a BIA workshop, using the BIA tool presented Figure 7. The product lifecycle phases that were identified in the CSL are shown on the left side of the tool, and the valuation is done according to company-specific criteria, such as quality, time, carbon footprint, or price, as shown in Figure 7.

Valuation	One time investment	Annual investment	€	Total
<b>Price</b>			-550 000 €	-550 000 €
What is the impact of new technology to the cost of the product?				
<b>Sales</b>			20 000 €	20 000 €
What is the impact of new technology to the sales?				
<b>Project management</b>				0 €
What is the impact of new technology to the project design and control?				
<b>Business contracts</b>				0 €
What is the impact of new technology to the business contracts?				
<b>Documentation</b>		-30 000 €		-30 000 €
What is the impact of new technology to the documentation?				
<b>Purchase</b>				0 €
What is the impact of new technology to the purchase?				
<b>Manufacturing</b>	900 000 €	120 000 €		1 020 000 €

Figure 7. An example of a business impact analysis (BIA) template.

The managers who were involved in the CSL workshop that defined the targets are recommended as participants, since they have the best knowledge regarding the potential effects of technology in the valuation context. The contribution of step five to KM is presented in Table 7.

Table 7. The contribution of step five to knowledge management (KM) for sustainability.

Knowledge Type	Key Knowledge	Acquiring the Knowledge	Using the Knowledge
Key individual knowledge	Accounting data Knowledge about business contracts Effects on product lifecycle processes	From manager(s) in the BIA workshop	To form a shared understanding of the economic effects of technology
Key organizational knowledge	Shared understanding and common agreement regarding the potential and business effects of technology	From manager(s) in the BIA workshop	Supporting decision making related to technology

#### 4.6. Communicating the Value of Technology

The final step of the TVM is communicating the value of technology. In practice, this is the final report that documents the knowledge acquired during the process. From the KM perspective, this step enables the development of knowledge when it is available to the relevant participants. There are no specific guidelines regarding how this step should be carried out. It is dependent on company policies and the final use of the acquired knowledge. A summary of the knowledge related to step six is presented in Table 8.

Table 8. The contribution of step six to knowledge management (KM) for sustainability.

Knowledge Type	Key Knowledge	Acquiring the Knowledge	Using the Knowledge
Key individual knowledge	-	From documentation produced in steps one to five in the TVM by the facilitator	Communicating the knowledge related to the technology decision
Key organizational knowledge	Business targets (CSL) Design knowledge (DRP) Economic impact (BIA)	-	Supporting decision making related to technology and improving knowledge

## 5. Discussion and Conclusion

This paper proposes a novel TVM to support KM in technology decisions to improve sustainability by using approaches from design science [31]. The paper focuses on the acquisition and use of knowledge and the economic aspects of sustainability, as well as on societal and environmental aspects, which can be taken into account during the evaluation. Based on three case studies that were carried out, the TVM supports the acquisition and use of knowledge to improve sustainability.

The main contribution of this paper is its focus on the product, including the properties and behaviors of a technical system in KM, in order to make the assumptions behind the technology valuation visible and put them under analysis. Sustainability defines the business goals and targets of a product. The behavior of a product has a direct effect on sustainability—for example, the price of a product (economic perspective) or the contamination associated with a product (environmental perspective). The behavior of a product is caused by properties that the designer can directly affect. Technology can change the properties of a product, and by understanding the previously mentioned cause–effect link, it is possible to evaluate the sustainability of technologies in a specific environment. To gain sustainability, the TVM focuses on aspects similar to those of the methodology proposed by Battagello et al. [38] for supporting make/buy decisions: connectedness, strategic value, and magnitude.

Regarding the definition of the method by Newell [22], the TVM fulfills all four statements. The proposed TVM can be seen as a specific way to proceed, since it is focused on supporting technology decision making in product development toward sustainable goals in each business situation and environment. Second, it is based on design science [31], which strongly guides the proceedings. Technology decision making [9] defines logical steps, including the determination of criteria and the evaluation of alternatives where they are supported by the proposed TVM. Theories from EDR also support the rationale for the proposed TVM. A description of the proposed TVM is given in Section 4, and the subgoals and subplans of the method are also shown. The occurrence of TVM can be evaluated according to the outputs of the method, such as the design reasoning pattern, which is also presented in Section 4.

RQ1 asks, “what is the key individual and organizational knowledge needed in technology valuation to make the assumptions visible in order to support sustainability?” Knowledge gathering begins with targets for sustainability, which commonly originate from managers and are thus classified as individual knowledge. The knowledge about the targets should be collected and made visible to all participants after it is commonly accepted and can be used as organizational knowledge. After the targets are set, the knowledge related to the product is collected and modeled. This includes the properties and behaviors of the product, causing the targets to be defined first. The analogy to the target setting phase is obvious—the gathering of information starts with individuals and continues onto the organizational level. This makes possible the formation of a common understanding. Finally, the accounting data related to business contracts are considered when the valuation of technology is undertaken. The knowledge is based on EDR theories [15,18] and, more specifically, on research carried out in a technology evaluation context [32].

RQ2 asks, “how can the key individual and organizational knowledge be acquired?” To acquire the key knowledge, the proposed TVM includes six steps with specified tools and outputs. Proposed tools, such as the CSL and DRP, guide conversation in the workshops and support knowledge acquisition. The knowledge gathered is mainly tacit knowledge, and therefore the workshops are the main tools used for this purpose. It is preferable that this facilitation is undertaken according to the systems-based technocratic school and the spatial-based behavioral school described by [27], and that physical and mental space are used [28].

RQ3 asks, “how can this key individual and organizational knowledge be used in decision making?” Knowledge acquisition proceeds step by step in the TVM, and the acquired knowledge from the previous step is used to support the next step. Finally, when all the required knowledge has been acquired, modeled, and accepted, it can be used to support the technology decision. Individual tacit knowledge is transformed to individual explicit knowledge and group and organizational knowledge,



according to [29]. In addition, according to [9], using the gathered knowledge supports the rational decision-making approach.

When evaluating the validity of the results, tacit knowledge is captured, modeled, and validated with the company personnel in the workshops. This is generally where the best available knowledge can be found. The main focus of this research is to support technology decision making for sustainability. The gathered knowledge is traceable, since the origin and rationale of the information is known and modeled. This approach enables an evaluation of the validity of the knowledge. Importantly, when information is documented and commonly accepted, the correction and improvement of knowledge also becomes possible, which supports the goal of sustainability. This method is also seen as beneficial for communication when evaluating the factual possibilities related to technologies [39] by using a pragmatic constructivist approach [40]. Product properties and behaviors are linked to all functions within companies and, therefore, TVM is seen as a tool for communication that can support knowledge acquisition.

The reliability and limitations of this research were evaluated from two perspectives. First, regarding the reliability of the proposed TVM, three case studies were undertaken; therefore, it is difficult to generalize the results, although the TVM was beneficial in all three case studies. This method relies heavily on workshops, and the know-how and capabilities of the facilitator or company personnel can affect the results. Additionally, the capabilities of company personnel to reach a joint understanding about the DRP model and dispositions can affect the reliability. Accordingly, it is possible that not all of the significant information was acquired, or that the DRP model is not fully valid. The proposed TVM is based on understanding the product properties and behavior to describe its dispositions. Therefore, if the product and technology being evaluated does not have these dispositions or the required knowledge is not available, this method cannot be used. Second, regarding the reliability of the research approach, case study research was selected, and therefore, the difficulties with generalization also exist in this perspective.

The proposed TVM can be used to achieve sustainability by supporting technology decisions. The knowledge acquired during the process relates to business and product modeling, which supports not only an understanding of technology, but also an understanding of the main elements that create potential benefits for the examined company. With this knowledge collected, it is possible to evaluate other actions to improve the performance of the company. It is recommended that future research test the proposed TVM in different contexts with different technologies to improve these tools so that they are easier to use.

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