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A System Thinking Normative Approach towards Integrating the Environment into Value-Added Accounting—Paving the Way from Carbon to Environmental Neutrality

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Abstract: Life Cycle Assessment (LCA) is increasingly being applied in corporate accounting. Recently, especially carbon footprinting (CF) has been adopted as 'LCA light' in accordance with the Greenhouse Gas Protocol. According to the strategy 'balance, reduce, substitute, compensate', the approach is intended to provide the basis for optimization towards climate neutrality. However, two major problems arise: (1) due to the predominant focus on climate neutrality, other decisive life-cycle impact categories are often ignored, resulting in a misrecognition of potential trade-offs, and (2) LCA is not perceived as an equal method alongside cost and value-added accounting in everyday business, as it relies on a fundamentally different system understanding. In this paper, we present basic considerations for merging the business and life-cycle perspectives and introduce a novel accounting system that combines elements of traditional operational value-added accounting, process and material flow analysis as well as LCA. The method is based on an extended system thinking, a set of principles, a calculation system, and external cost factors for the impact categories climate change, stratospheric ozone depletion, air pollution, eutrophication and acidification. As a scientifically robust assessment method, the presented approach is intended to be applied in everyday operations in manufacturing companies, providing a foundation for a fundamental change in industrial thought patterns on the way to the total avoidance of negative environmental impacts (i.e., environmental neutrality). Therefore, this is validated in two application examples in the German special tools industry, proving its practicability and reproducibility as well as the suitability of specifically derived indicators for the selective optimization of production systems.

Keywords: environmental management accounting; externalities accounting; sustainable manufacturing; climate neutrality; environmental neutrality

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Citation: Miehe, R.; Finkbeiner, M.; Sauer, A.; Bauernhansl, T. A System Thinking Normative Approach towards Integrating the Environment into Value-Added Accounting—Paving the Way from Carbon to Environmental Neutrality. *Sustainability* **2022**, *14*, 13603. https://doi.org/10.3390/su142013603

Academic Editors: S. Mahdi Homayouni and Hamid Reza Panjeh Fouladgaran

Received: 30 August 2022
Accepted: 18 October 2022
Published: 20 October 2022

1. Introduction

Sustainability is an inherent challenge in future industrial production. Ever since its baseline concept was published over 40 years ago [1], its operationalization to business practice has been massively hindered by the vague formulation of the basic concept [2]. Especially the enforcement of the triple bottom line interpretation (weak sustainability), which led to the possibility of asserting subjective demands and, thus, to a dilution of the overall concept [2–6]. Questions of social and environmental impact thus continue to receive far less attention in the operational decision-making process than economic benefits. While integration into business management is now common practice in companies, especially when certification and/or reporting (e.g., according to GHG Protocol, ISO14001, EMAS, CSR) are pending, its results rarely lead to decisions that are appropriate in the sense of a regulative economy, be they within the framework of planetary boundaries or socially accepted target conditions [7]. A stricter integration of ecological and social aspects into corporate accounting has been the subject of intense discussion in the scientific community for decades now, including under the term social entrepreneurship [8], leading to a multitude of methodical approaches. However, two major problems remain, which have not been comprehensively addressed in either life-cycle engineering (LCE) or environmental management accounting (EMA) [9–15]:

(1) Due to the predominant focus on climate neutrality in the contemporary manufacturing industry, carbon footprinting (CF) is a far more common concept in business practice than a complete LCA. This restriction to a single-impact category results in a misrecognition of other life-cycle impact categories. Potential trade-offs are often not understood, and thus ignored.
(2) Although standardized in the early 2000s [16,17], LCA is not perceived as an equal method alongside cost- and/or value-added accounting in everyday business, but as a stand-alone approach. This is mostly due to the fact that it relies on a fundamentally different system understanding to traditional business accounting. Today, LCA results are often compared with costs in complicated cost-impact diagrams, which represent a weak precondition for an equal consideration of economic, ecological and social factors. Another alternative is the monetarization of externalities, for which basic approaches exist (e.g., abatement and damage costs). However, only a few methodological frameworks are available for an effective integration into corporate accounting, which represents the main source of decision-making in day-to-day operations.

In this paper, we thus raise the question what exactly the 'value-added of production' from an economic and ecological perspective is? Thereupon, we analyze to what extent current theories and concepts of (business) economics reflect the question of an integrated understanding of value and how an integrated value-added accounting system should be designed. The research process of this work follows the standard approach of real sciences according to Ulrich and Hill [18]. The aim of this work is to execute subjectively perceived sections of reality by describing and defining concepts, to abstract on the basis of individual cases and to develop alternative courses of action for the realization of future realities.

This paper documents the investigation of the status of integrating ecosystem services into business value-added accounting and the development of a method for measuring the economic-ecological value-added of production systems. Thus, it adopts a semi-systematic review approach to reduce bias due to a selective literature choice and to increase the reliability of the literature choice according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. By identifying the essential issues of integrated sustainability accounting, a search string for a literature review was developed. The search was conducted in electronic literature databases including Google Scholar, Semantic Scholar, Scite, WorldWideScience and Fraunhofer Enhanced Library (eLib). The keywords for the search process resulted from a panel of three experts in the fields of production engineering, business accounting and sustainable engineering, who also reviewed the literature selection. Similar approaches are well documented in the literature [19,20]. The synthesis ofthe results provides the basis for the developed accounting system.

2. Fundamental Considerations

2.1. A Brief History of the Concept of Value in Society and Economics

The concept of value is complex and influenced by different disciplines as well as religion and human perception. A common interpretation for the term does not exist. The perception of value represents an intersubjective entity, i.e., it is neither purely subjective nor completely objectively measurable [21]. Rather, the value of a given object emerges when a certain number of people believe in it. Our ideals are decisive in this. However, they differ considerably depending on the point of view (e.g., individual, company or society) and the timeframe (what is 'in vogue' in the current generation).

Ideals, in the sense of morally good attributes, are usually a subject of investigation in ethics. The answer to the core question of practical ethics, which actions are considered morally valuable, is known as the "golden rule". In the form of a positively or negatively formulated maxim, it appears in almost every moral–ethical or religious treatise. A particularly prevalent representative of moral ethics is Immanuel Kant, who stated that moral actions in a society (which must also include industrial value creation) must always follow a categorical maxim. While, for Kant [22], a moral action manifests itself only in the here and now, Jonas [23] advocates an expansion of the space of observation. In times of increasingly evident damage to the ecological and social environment, it is no longer just the here and now that is relevant, but also the consequences of action. According to Jonas' principle of responsibility, an action is to be regarded as moral if it is in harmony with the permanence of human life.

The economic perception of value is largely based on classical and neoclassical theories [24]. Thereby, two fundamental approaches are distinguished: objective and subjective value theories. The objective value theory comprises a number of approaches to describe a good's real monetary value. The first approaches date back to Locke's natural value theory, which derives the human right to property from the work performed [25]. Among its most prominent representatives are Smith [25], Ricardo [26] and Marx [27]. The latter, for the first time, emphasized the dependence of economic value creation on social paradigms. In contrast, the subjective value theories focus on an individual utility as the central object of investigation. These theories do not consider absolute values but infinitesimal changes in utility. The central instrument of subjective value theories is the marginal principle, dating back to von Thuenen in the 19th century [28]. Closely linked to the concept, which was further developed by leading figures such as Jevons, Menger and Walras [29–31], is the already rejected economic concept of the rationally acting individual. This homo oeconomicus assigns a value merely to the next infinitissimal benefit, to be represented in monetary units.

In early economic theories, nature was of secondary importance. For example, Smith places emphasis on individual utility, which, assuming full competition, adds up to a collective optimum of prosperity [25]. The decisive factor here is the scarcity of goods. Believing that nature exists infinitively, it is regarded as free of charge. If a good is free, it has no monetary value. This did not change until the 1950s with the emergence of ecological and environmental economics and industrial ecology, predominantly influenced by Kapp [32]. Ecological economists are deeply concerned with the role of limited natural conditions for production [3,33]. The classic concept of ecological economics is the idea of sufficiency. Representatives of this school include Socolow et al. and Bartelmus [34,35]. In contrast to neoclassical economics, they emphasize that production depends on non-reproducible resources that cannot be replaced by human labor and technology. The main question in the value debate among ecological economists is whether the direct attribution of economic value to nature is the most logical and meaningful way to incorporate this concern for limited natural conditions into the analysis of the market valuation of nature and contemporary environmental problems [36].

2.2. The Value-Added of Production

As with the concept of value, no common interpretation exists for the term value-added [37]. Various authors identify value creation, in the sense of generating value through the planned combination of production factors, as the core objective of all production [38–41]. Porter understands value-added within a company as a sequence of certain activities in combination with the profit margin [42]. While Porter reduces the term to a purely financial value, Westkämper emphasizes that the added value can be both monetary and functional [40,42]. According to the lean management philosophy, manufacturing companies in the last 30 years have largely streamlined their businesses towards the perception of value by the customer [43]. According to Zeithaml, four types of value perception by the customer may be differed: (1) sacrifice of low price, (2) benefits of the product, (3) quality obtained for the price paid, and (4) total benefits obtained for total sacrifice incurred [44].

Although manufacturing is a process dedicated to the satisfaction of human needs within the life-cycle of products, it may have a lower or higher value for the ecosystem depending on the degree of environmental impact. Consequently, production researchers have recently outlined the concept of a positive impact factory, which serves as an emissions and waste sink (but, in most cases, is far from industrial application) [45,46]. Various authors have attempted to describe the value of nature (e.g., ecosystem services) [47–49]. However, crucial to this work is the way nature is classified in terms of production. Approaches to the classification of nature can be found under [50–52]. The most elementary classification is that of life-cycle engineering, i.e., the subdivision of nature into impact categories perceived by humans.

In this paper, we interpret the value of production as a categorical maxim of an action that is desirable from an economic and ecological perspective. Thereby, we assume that it is possible to quantify its magnitude in monetary terms. From an anthropocentric point of view, the integrated value of production is the quantity of monetary units that both a company and society contribute to production.

2.3. State of the Art of Operational Added Value Calculation

The value-added today is a central measure of the performance of an economic unit [53]. Its quantification in the business context is carried out in the operational value-added calculation [54–56]. The approach is regarded as a special case of corporate accounting (largely differing from cost accounting), as it can be used for both external and internal accounting. However, a uniform accounting system does not exist. The reason for this is the lack of a consistent definition of business and intermediate consumption. Existing concepts of operational value-added calculation can be classified according to their horizon, which can be narrow or broad. The narrow understanding calculates the operational value-added from the sum of profits, wages and salaries. The broad understanding is based on the consideration of the difference between gross profits and intermediate consumption. Similar to national accounts, gross profits are calculated by sales minus increases in stocks of finished and unfinished goods and the equipment produced for own use. The intermediate inputs of other companies are understood as material costs, depreciation, external, field service and risk costs [57].

A growing number of researchers have investigated the design and implementation of accounting practices that address environmental issues [58–64]. However, virtually all work that aims at a monetary internalization of externalities into the business accounting can be attributed to full-cost accounting (i.e., not value-added accounting). The first works originate from the late 1980s and early 1990s. To date, several approaches have been presented. These include ecologically oriented cost accounting, Full Cost Accounting (FCA) at Ontario Hydro, Costs of Environmental Effects (CEE) at the Dutch BTO Origin, Prevented Environmental Costs Accounting at the German Neumarker Landsbräu brewery, Integrative Environmental Cost Accounting, Sustainability Cost Accounting and Environmental Management Accounting (EMS) [65–71]. External effects are internalized either by abatement or damage cost approaches (i.e., willingness-to-pay/sell), the two most common methods for the monetization of external effects [72,73]. While the former seeks to estimate the caused damage, the latter can be understood as the costs of prevention. More recent, similar concepts for monetizing environmental impacts, especially in the context of capitalizing and managing “commons” such as forests, lakes, rivers, and the atmosphere, were presented under terms such as natural capital accounting or payments for ecosystem services [74–79].

Another stream of thought is life-cycle costing (LCC) that is not assigned to environmental cost accounting in the literature. Although it is not intended ab initio, it in principle enables the internalization of external environmental effects [80]. However, this is also possible by means of an additional LCA, in conjunction with abatement or damage cost approaches (see Eco Costs 99, Environmental Priority System) [81,82]. In addition, the aim of an LCC is not to record the environmental impacts within a company and allocate them in monetary values to cost centers and products, but to identify potential for the improvement of a single product across its entire life cycle.

Approaches with a genuine focus on integrating the environment into operational value-added accounting are rare. Of particular significance in this context are the concepts of environmental and sustainable value-added [79–84]. Sustainable value-added represents the relationship between the value created by the company and the damage it causes, as well as that of a benchmark. Previous periods, similar competitors or the company's sector can be used as a benchmark [83]. Similar concepts, representing a ratio of generated value and associated environmental damage, have been presented under the terms green or net value-added, natural and/or true value accounting [84,85]. Although the concepts explicitly include ecology in the operational value-added calculation, they are indicators that are limited to the company level. On this basis, an allocation at the product or process level is hardly possible. No consistent procedural method is presented for quantifying ecological value.

3. Results

3.1. *eco^2-Value-Added Approach*

3.1.1. Extended System Understanding

Fundamental to the development of a categorical interpretation of value creation in manufacturing companies is an understanding of systems that goes far beyond the scope of conventional business administration. Therefore, it is essential to develop an understanding that combines the views of conventional business administration with the systemic understanding of ecology and the priority model of sustainability. According to systems theory, the designation of the surrounding systems and the specification of the recurring interactions between the subsystems are decisive [86].

Human existence is based on certain natural conditions, summarized here in the system of the ecosphere. As such, it comprises all animate and inanimate elements of the system earth. In this understanding, human existence represents a sub-section of the ecosphere, which will be referred to as the anthroposphere. The anthroposphere is, in turn, divided into two subsystems: economic and social. An enterprise represents a manifestation of human existence and is assigned to the anthroposphere. In systems theory, a company is initially regarded as a black box, whose core objective is to create value. In order to achieve this goal, certain input variables are required and, through their combination, certain output variables are generated. The company obtains input variables from the markets of the economic and social system and the ecosphere. Similarly, output variables are supplied to the markets of the economic and social system and the ecosphere. The potential effects of the production of goods and services on the eco- and anthroposphere are covered by the impact system. In addition, a fictitious impact system is required to record the impact of producing goods and offer services on the eco- and anthroposphere. This is initially assigned to the ecosphere, but has various exchange relationships with the anthroposphere. The ecological consequences of extraction (source function) or release (sink function) can cause problems at the global and local level. The impact system is, therefore, further subdivided into global and local systems. The interaction of a company and its surrounding systems takes place as information and real or nominal goods flow. The interaction of a company with its impact system represents a special case of relation as it is solely based on the transfer of real goods that each generate a nominal flow of goods, mostly with a certain time lag, i.e., external costs. These, however, generally do not affect the company itself but other systems of the anthroposphere. Figure 1 illustrates the extended system understanding that sets the basis for an integrative value-added accounting scheme.

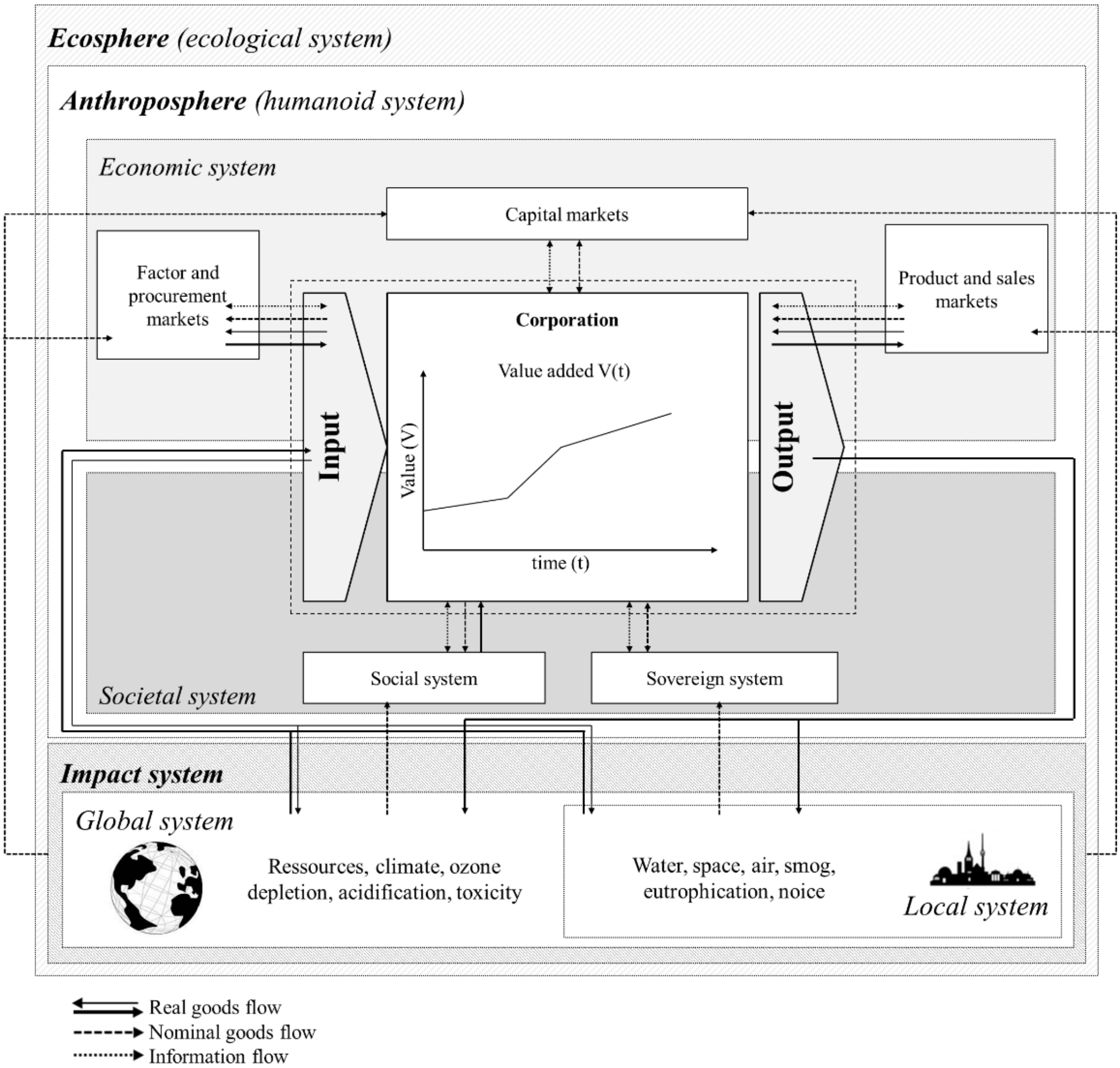

Figure 1. Extended system understanding of an integrated value-added accounting.

3.1.2. Premises of an Integrated Value-Added Accounting

The accounting system presented here follows six principles that serve hermeneutical and/or procedural functions (for details, please see Supplementary Materials):

- Value principle: A production–economic activity never exclusively serves the satisfaction of individual needs, but must ensure that its consequences are justified in terms of socially accepted standards. In order to meet this requirement, the sustainable production value of a productive activity is defined as the sum of economic value and natural value.
- Sustainability principle: A production–economic activity at the economic–ecological interface is considered sustainable if the difference between external production value and value consumption is greater than or equal to zero. There are only two possibilities for sustainable value creation from a business perspective: An action has a positive natural value, or a company specifically pays the natural debt it has caused.
- Superposition principle: Both the amendment and damage cost approach are rejected as insufficient for internalizing external costs. Since it is impossible to predict whether the solution to the environmental problem will be achieved by avoiding, adapting to and accepting the damage, a paradox arises that essentially relates to Schrödinger's cat. As the solution of the environmental problem is currently conceivable by prevention and by acceptance of the damage, both conditions must be considered equally.

- Materiality principle: Since it is rarely possible to identify all the actual consequences of an action, an iterative approach is needed to calculate the NV. If the cause–effect chain of an action is very complex, the first step is to focus on the significant damage.
- Damage occurrence principle: Environmental impact does not necessarily result in damage. From the perspective of the system under consideration, however, this is irrelevant. Similar to the superposition principle, there is no clear tendency of whether a damage occurs or not. Therefore, it is assumed in principle that the damage will occur.
- Co-production principle: A production process is to be understood as co-production in any case.

3.1.3. Generic Procedural Approach

The generic approach combines elements of traditional operational cost accounting, calculatory value-added accounting, process and material flow analysis, as well as life-cycle assessment, and complements these at selected points. As a measure of sustainable value creation, the eco^2 value-added (e^2VA) is introduced, which is calculated from the difference between the production value (PV) and the value consumption (VC), i.e.: $e^2VA = PV - VC$. In the sense of the extended system understanding, two subsystems are distinguished. The internal system (I) characterizes the company as such. It is sufficiently described by its own system boundaries. The external system (E), on the other hand, is the embodiment of the previously introduced impact system, the system boundaries that differ according to the considered impact category. The distinction between the two systems requires a separate calculation and comparison of PV and VC, i.e.: $e^2VA = \left[PV^{\mathbb{I}} + PV^{\mathbb{E}}\right] - \left[VC^{\mathbb{I}} + VC^{\mathbb{E}}\right]$. In order to comply with the previously formulated sustainability principle, the system aims at a completely impact-independent production. In the following, this objective is referred to as the externality condition, i.e., the target of external value-added (EVA) is ≥ 0, i.e.,: $EVA = PV^{\mathbb{E}} - VC^{\mathbb{E}} \geq 0$. If the externality condition is not fulfilled, a socially perceived reduction in natural value occurs.

Regarding its application to any object of investigation, the question arises as to which information of the internal and external system is relevant and how they correlate. Since the approach can be applied in a variety of cases, the object and system under investigation must first be specified. As a result of the wide range of methods for implementing the conceptual principles described below, a selection must then be made depending on the internal and external system that is described in detail. Likewise, the composition of the $PV^{\mathbb{I}}$ in relation to the object of investigation can differ considerably. The target system of the study is to be designed congruently. Thereupon, the environmental problems perceived by society and preferred environmental constitutions must be quantified. For this purpose, an according socio-economic analysis has to be carried out. The aim is to calculate socially effective procurement prices in line with the German Federal Environmental Agency (UBA) [57,86]. In order to be able to allocate these prices to consumption according to their cause, the quantity structure of the object of investigation is of essential importance. After this, the basic considerations outlined above can be made in the form of an extended operational value-added calculation and interpreted with regard to their legitimacy, optimization potential, etc. Figure 2 summarizes the generic procedure in nine steps.

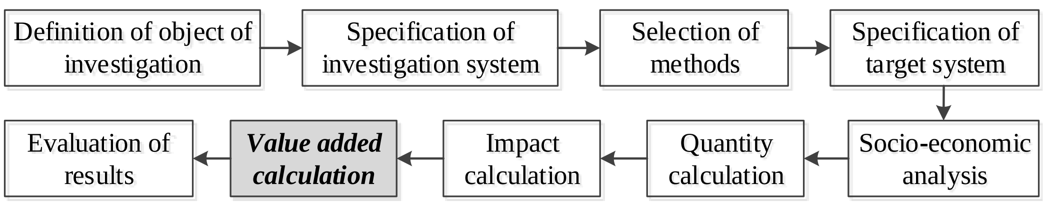

Figure 2. Generic procedure to quantify the e^2VA.

The first step is to determine the object of investigation. It serves as a basis for the assessment of the value-added. The procedure proposed serves various purposes at different points in time in the sequence of the operational service creation process at different object levels. The latter comprises the system (company) and its subsystems (business area, product, process). The points in time in the sequence of the operational service provision process depend on the choice of object. While a product stands on its own (here, only the life-cycle is relevant), the choice of the points in time in all other cases requires a different balancing limit of the external system. In the case of the production process, the product development, production and end-of-life phases are the main areas of consideration. In the case of the company, these are either the entire life phase (foundation-to-liquidation) or a certain phase of existence (e.g., operating year, quarter). The purpose can be a comparison of alternatives, e.g., between products, technologies or companies, the identification of essential levers of optimization, speculation on a future development or the legitimization of an operational action from the perspective of sustainable value creation.

Second, the internal and external system must be specified. Their particular characteristics dictate the use of the methods of quantity, impact and value-added calculation. The internal system describes the production methods, principles and concepts used. Types of production are single-part, repetitive, variant, series or mass production. The production principles include construction site production, workshop principle, production cells, flexible systems and flow principle [40]. Last, but not least, the manufacturing concepts consider the decoupling of production with regard to customer requirements. A distinction is made between make-to-stock, assemble-to-order, make-to-order and engineer-to-order. After describing the internal system, its interaction with the external system must be characterized. Therefore, a separation of foreground and background system is advised. The latter can again be divided into upstream and downstream systems [87]. The decisive factor for the choice of system boundaries of foreground and background systems of individual production factors is the competence principle.

Methods for calculating internal and external value-added are selected by a range of approaches that exist in the majority of cases. While the calculation of $PV^{\mathbb{I}}$ and $VC^{\mathbb{I}}$ of an enterprise can follow the pattern described above, the investigation of a subsystem of the organization (product, process) requires a proper allocation of $PV^{\mathbb{I}}$ and $VC^{\mathbb{I}}$. For this purpose, the present work recalls on traditional cost accounting. The essential structures are already established in many companies. The distribution of production value and value consumption types to a product or process is carried out according to the specifications of the internal system using divisional, overhead or joint costing. As a method for determining $PV^{\mathbb{E}}$ and $VC^{\mathbb{E}}$, a life-cycle assessment is to be applied [52].

The target system in the context of sustainable value creation is fully described by the respective purpose with regard to the internal and external system. The target system of the internal system varies depending on the object of investigation. In comparison to the consideration of the entire enterprise system, in which the revenue for co-products and recyclable waste is usually known through accounting, the subsystem must be oriented to the co-production principle formulated at the beginning. Thus, it must first be examined whether co-products and recyclable waste are generated. If this is the case, they are to be valuated at market prices and integrated into the cost estimate. In the case of the external system, the derivation of $PV^{\mathbb{E}}$ represents a high hurdle. In essence, it is necessary to answer the question of what benefits a production-related action can provide with regard to specific environmental problem areas. Two options can be derived from the principle of sustainability: (1) A production does not contribute in any way to all known environmental problems—which is not very likely at present—or (2) the company contributes actively to solving the environmental problems it has caused. The latter can happen in two different ways. On the one hand, the use of certain internal input and/or output variables can contribute to the realization of one or more socially preferred environmental states, e.g., Zhu et al. demonstrate certain positive effects of individual greenhouse gases on the growth of certain plants, which, in turn, contribute to the solution of the environmental problem of climate change [88]. If such a benefit from a contribution is known, adequate credits, depending on the interactions, are to be considered in the accounting system described below. Although this possibility exists theoretically, its practical implementation is difficult to realize due to the current lack of knowledge of the interrelations and the corresponding data situation. On the other hand, an organization can pay the "environmental debt" by investing specifically in the external solution (e.g., climate fund, compensation agencies). Of course, this alternative, which is currently far more realistic, would have to be geared to the level of the claim caused by each environmental problem area (including climate change and acidification).

The socio-economic analysis provides a monetary representation of the external system in terms of the environmental problems perceived by society and its preferred target states, the damage incurred and the respective opportunity in the form of external procurement prices ($p^{\mathbb{E}}$). Target states can be the pre-industrial level, the ecological limits of the earth and socially accepted target states in the form of laws, regulations, contracts or standards. Depending on the reference, the calculation of the ${p^{\mathbb{E}}}_{ct}$ of a desired target state of an environmental problem area (c) in any period (t) differs. The total external value-added (EVA_{ct}) is then set either in relation to the quantity of a reference indicator (${Q^{\mathbb{E}}}_{ct}$) or the corresponding target value of the period (${E^{\mathbb{E}}}_{ct}$) used in the same period, i.e.,:

$${p^{\mathbb{E}}}_{c} = \frac{{EVA^{\mathbb{E}}}_{ct}}{{Q^{\mathbb{E}}}_{ct}} \text{ or } {p^{\mathbb{E}}}_{c} = \frac{{EVA^{\mathbb{E}}}_{ct}}{{E^{\mathbb{E}}}_{ct}}$$

The reference indicators are primarily the total quantities of an equivalence factor of a certain effect category within a certain period. In our supporting materials, we provide a detailed application example of the socio-economic analysis based on 12 distinct market models to calculate $p^{\mathbb{E}}$ for the impact categories climate change (GWP), stratospheric ozone depletion (ODP), air pollution (APP), eutrophication (EP) and acidification (AP). Here, the external procurement prices are estimated for the reference year 2014 and projected until 2050 with regard to key reference indicators such as population growth and GDP. The authors do not claim a universal validity of the prices, but rather deepen the calculatory approach presented here in a detailed example. Table 1 summarizes the results.

Table 1. Summary of ${p^{\mathbb{E}}}_{ct}$ between 2014 und 2050 (for details of calculation, please see Supplementary Materials).

	Unit	2014	2020	2030	2040	2050
${p^{\mathbb{E}}}_{GWP}$ (nominal)	[€/kg CO_2e]	0.048	0.055	0.071	0.092	0.120
${p^{\mathbb{E}}}_{GWP}$ (real)	[€/kg CO_2e]	0.048	0.043	0.036	0.032	0.028
${p^{\mathbb{E}}}_{ODP}$ (nominal)	[€/kg R11e]	559.191	667.585	1003.761	1870.942	3577.393
${p^{\mathbb{E}}}_{ODP}$ (real)	[€/kg R11e]	559.191	590.441	675.936	800.592	934.180
${p^{\mathbb{E}}}_{APP}$ (nominal)	[€/kg PM2.5e]	118.788	163.948	286.731	478.473	791.136
${p^{\mathbb{E}}}_{APP}$ (real)	[€/kg PM2.5e]	118.788	137.948	194.003	274.559	404.452
${p^{\mathbb{E}}}_{EP}$ (nominal)	[€/kg ${PO_4}^{3-}$e]	8.700	12.204	21.279	36.775	63.099
${p^{\mathbb{E}}}_{EP}$ (real)	[€/kg ${PO_4}^{3-}$e]	8.700	11.073	16.415	24.117	35.175
${p^{\mathbb{E}}}_{AP}$ (nominal)	[€/kg SO_2e]	2.938	4.352	8.391	16.213	31.396
${p^{\mathbb{E}}}_{AP}$ (real)	[€/kg SO_2e]	2.938	3.586	5.936	9.828	16.276

Subsequently, the quantity analysis of the internal system takes place in the form of an input–output analysis according to Leontief [89]. The quantity concept is based on an extended understanding. It describes a grouping of distinguishable objects to form a whole. Thus, it is not only necessary to include physical quantities of substances and materials remaining in the product and its by-products, but also factors such as place and time of consumption, chemical composition of the substances and materials, the person performing the work, frequency of use (especially means of production), etc. The quantity calculation regarding a specific output volume (functional unit) results in a e × a entity–activity-matrix of period t (EA_t), which is the product of the entity activity vector of period t ($\overline{ea}_t$) and the transposed entity vector ($\overline{e}^T$):

$$EA_t = \overline{ea} * \overline{e}^T = \begin{bmatrix} r^{\mathbb{I}}_{o_{11}} & \cdots & r^{\mathbb{I}}_{o_{1b}} \\ \vdots & \ddots & \vdots \\ r^{\mathbb{I}}_{o_{e1}} & \cdots & r^{\mathbb{I}}_{o_{eb}} \end{bmatrix}$$

Based on the input and output quantities initially determined for the internal system, the external impact quantities ($i^{\mathbb{E}}_p$) are derived. For each socially perceived environmental problem (c), a classification and characterization must first be carried out in the sense of traditional life-cycle assessment. The input–output analysis carried out previously can be regarded in this context as a life-cycle inventory. In this sense, the $i^{\mathbb{E}}_p$ results as a function of the internal input ($r^{\mathbb{I}}_p$) and output variables ($x^{\mathbb{I}}_p$). The impact potential in relation to a socially perceived environmental problem and/or a socially desirable target state is represented by the binary problem impact coefficient (z). The contribution of the internal input and output variables to an environmental problem c is recorded using the problem constant k, which is essentially the equivalent of the characterization factor of an LCA study. The impact quantity $i^{\mathbb{E}}_{p\,c}$ related to a socially perceived environmental problem c is:

$$i^{\mathbb{E}}_{p\,c} = f\left(r^{\mathbb{I}}_p;\ x^{\mathbb{I}}_p\right) = \sum\nolimits_{d=1}^{D} k_{dc} * \frac{r^{\mathbb{I}}_{p\,dc}}{z_{dc}} + \sum\nolimits_{f=1}^{F} k_{fc} * \frac{x^{\mathbb{I}}_{p\,fc}}{z_{fc}} \text{ with } c = 1, \ldots, C; d = 1, \ldots, D; f = 1, \ldots, F$$

The e^2VA can now be calculated as follows:

$$\begin{aligned} e^2VA &= PV - VC = \left[PV^{\mathbb{I}} + PV^{\mathbb{E}}\right] - \left[VC^{\mathbb{I}} + VC^{\mathbb{E}}\right] \\ &= \sum_{i=1}^{I} x^{\mathbb{I}}_{p_i} * s^{\mathbb{I}}_{p_i} + \sum_{c=1}^{C} i^{\mathbb{E}}_{p_c} * s^{\mathbb{E}}{}_c - \sum_{h=1}^{H} r^{\mathbb{I}}{}_h * p^{\mathbb{I}}{}_h - \sum_{i=1}^{I} x^{\mathbb{I}}{}_i * p^{\mathbb{I}}{}_i - \sum_{c=1}^{C} i^{\mathbb{E}}_{p\,c} * p^{\mathbb{E}}{}_c \end{aligned}$$

Based on the calculation, various indicators can be calculated for the evaluation and interpretation of the results. Similar to the ROI, for example, the sustainability coefficient is derived from the comparison of the external and internal value added. An assumed coefficient of −0.05 means that, in order to fulfil the externality condition, an amount of 5 cents per € of internal value-added should be paid in a targeted manner (i.e., for compensation) in line with the planning function. While the sustainability coefficient measures the extent to which a company actively contributes to the realization of an ecologically sustainable economy, the loss coefficient, caluclated as the ratio between external value consumption and the internal procurement price, illustrates the relative, non-priced contribution of any input quantity to the reduction in natural value. Further evaluations with regard to the dynamics, value-added deficit and resource efficiency of an e^2VA election problem cannot be further elaborated at this point.

3.2. Case Studies

The method was applied in a small company in the special toolmaking sector in Germany. In the first case, the method was used to investigate the sustainable value-added of the entire company. The second case compares two production processes of the same demonstrator via different technologies (ablative and generative methods).

3.2.1. Case Study 1: Company

The company (system boundary) that was investigated has 25 employees. The company's sales catalogue comprises around 11,000 products. The highly versatile production follows the workshop principle in batch sizes between 1 and 400. Accordingly, the production type consists of single-item and repetitive manufacturing. The manufacturing principles are primarily make- and engineer-to-order. The purpose of the calculation (target) was the verification of legitimacy of operational performance within a single operating year (observation period).

In the examined financial year, the company generated sales of € 1,792,926. Taking into account the total costs of € 1,508,497; this resulted in a profit (before taxes) of € 284,429. The market value of the equipment produced in-house was an estimated € 25,130, and that of the changes in inventories € 16,780. Interest on borrowings was estimated at € 1079. The internal value-added (IVA) of the production of goods and services in the period under review thus amounted to € 327,418.

The physical quantity calculation at the company level was divided into two sections. While a comparatively trivial input–output balance was sufficient for the consumption of raw materials, consumables, supplies and waste, quantity depreciations over their entire life-cycle had to be formed for buildings and operating materials. For this purpose, the quantitative depreciation of an operating asset or building was calculated from the quotient of input quantity and useful life. Since standard datasets for each machine were used to estimate the impact, no separate collection of the used materials and components was necessary. The useful life was based on standard depreciation. The building space (841 m^2) was integrated with a planned useful life of 60 years. The annual quantitative depreciation of the area was, therefore, 2.25 m^2 p.a. Table S1 in the Supplementary Materials summarizes the main consumptions of the I–O analysis of the internal system for the fiscal year under review.

To estimate the environmental impact, suitable and/or related datasets of the ProBas database were used with a suitable system boundary based on the CML method according to Heijung [90,91]. The operational performance in the reference year resulted in the following use of the external system: 225.6 t GWP, 765.5 kg AP, 12.6 kg ODP, 116.7 kg EP. The quantity categories (raw materials, auxiliary and operating materials, waste, operating resources) showed a divergent composition for each impact category. While GWP and AP emissions clearly resulted from the consumption of auxiliary and operating materials, the main sources of ODP and EP emissions were production waste. Operating resources also made a significant contribution to GWP emissions. In contrast, the firm's consumption of raw materials resulted in comparatively low physical use of the external system in the environmental problem areas of GWP and AP. By far the largest single polluters were electricity (GWP: 46.0%; AP: 60.1%; ODP: 36.5%; EP: 18.8%), production facilities (GWP: 15.8%; AP: 0.0%; ODP: 0.0%; EP: 0.0%), vehicles (GWP: 13.6%; AP: 9.8%; ODP: 0.0%; EP: 0.0%), mixed scrap (GWP: 6.0%; AP: 5.5%; ODP: 0.0%; EP: 0.0%), cooling lubricant waste (GWP: 4.7%; AP: 11.5%; ODP: 59.0%; EP: 75.5%) and aluminum (GWP: 4.5%; AP: 4.2%; ODP: 0.0%; EP: 0.0%). While the internal value-added amounted to € 327,418, the eco^2 value-added amounted to € 306,291. Since the organization did not positively contribute to the external system in the sense of e^2VA calculation, a reduction in natural value was determined amounting to € 21,127. The externality condition is, therefore, not fulfilled. Accordingly, the value-added is not sustainable. Figure 3 illustrates the composition of external system utilization by volume category. The sustainability deficit amounted to 0.07. In order to ensure sustainable value creation, 7 cents per € economic value-generated will have to be deducted as a benefit contribution in future. The most significant individual causes of the reduction in natural value are electricity (€ 9209.66), production facilities (€ 1707.33), vehicles (€ 1689.15), plastic, iron and mixed scrap (€ 1393.64) and waste-cooling lubricants (€ 238.08). The loss coefficient illustrates the relative, non-priced contribution of the individual categories to the reduction in natural value (electricity: € 0.22; production facilities: € 0.09; vehicles: € 0.29; plastic, iron and mixed scrap: € 1.21; cooling lubricant waste: € 0.16).

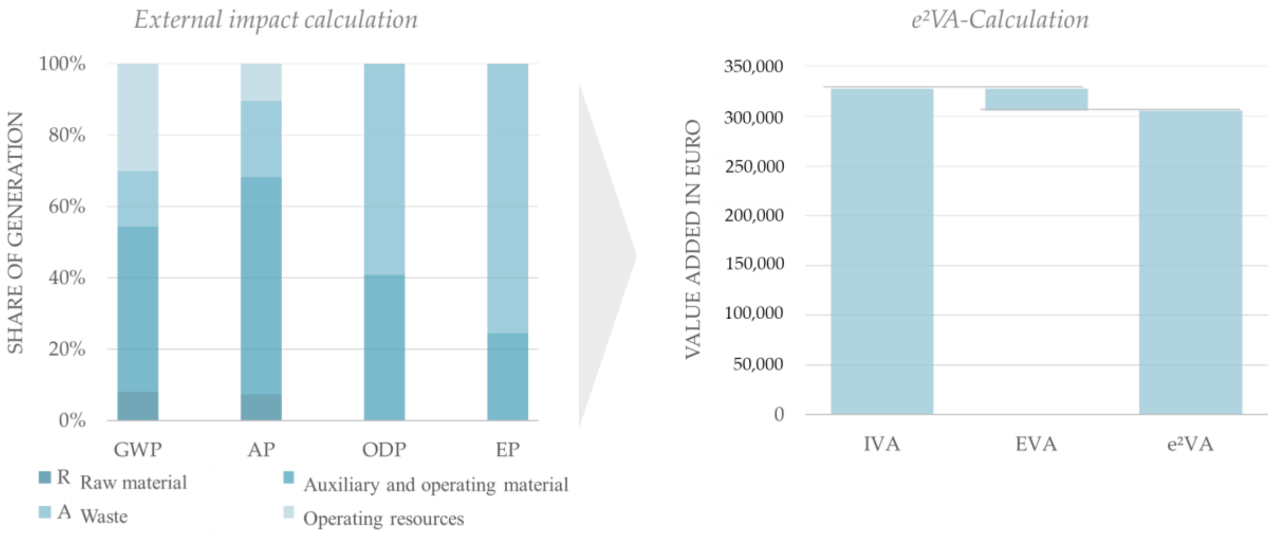

Figure 3. Evaluation of case study 1 (company).

3.2.2. Case Study 2: Process Comparison

The current machinery of the company includes the separating production processes turning, milling, sawing and drilling, the joining processes welding, soldering and bonding as well as the forming process eroding. In the course of its long-term strategic orientation, the company aims to acquire further manufacturing technologies (especially generative processes). For this purpose, a process comparison is needed. An assembly roller will be chosen as a reference product. This rolls the sealing rubber into the fixed cutout of the rear and driver's door during vehicle production. A reference scenario is to be investigated, in which the product is developed according to customer requirements and ordered with a batch size of 30 pieces (engineer-to-order). The current process, covering drilling, milling and turning, is to be compared with a fictitious additive process (here: fused deposition modeling). Therefore, the entire order process has to be mapped. As in the example above, all information used for the calculation is either taken from the documentation of the company or are publicly available data from third parties.

The boundaries of the production system depend on the specification of production types, production organization and principles as shown in the example above. In this sense, an overhead-based approach is chosen for the allocation of costs to the object under investigation. The primary goal of the production process considered here is the satisfaction of the customer's needs. The company calls for a price of 92.45 € per piece. For an order of 30 pieces, the primary output of the process amounts to 2773.50 €. Since only polyoxymethylen (POM) is used for the production of the component, the waste is only subject to costs. Therefore, a secondary output of the process does not exist. The sequence of the order process of both production variants (ablative and additive) is the same. However, the decisive difference between the two alternatives becomes clear when looking at the manufacturing process. Both the sequence and the quantity parameters differ. The procedure described above results in quantity structures for the two process alternatives documented in Table S2 in the Supplementary Materials.

The procedure of conversion using the ProBas data records was also used for the production alternatives examined here [91]. Table 2 summarizes the quantity-based usage of the external system for the two production types. While all parameters of the administrative process remained unchanged, the measures of the production process differed considerably. In terms of the effect on the external system, the ablative production was the more advantageous alternative. However, this is solely due to the comparatively long processing time for the printing and post-treatment, which resulted in a much higher electricity requirement.

Table 2. External process quantities per production type per piece (in kg).

	Ablative				Additive			
Type	GWP	AP	ODP	EP	GWP	AP	ODP	EP
Total	17.1	0.00838	0.000122	0.00112	22.7	0.0798	0.000476	0.00239

According to the company, the production value of the order consists of the sum of the turnover (€ 92.45 per unit; € 2773.50), the change in stock at market prices (10 units; € 924.50) and the pro rata offsetting of self-constructed assets (€ 25,130) and interest on borrowings (€ 1079). The direct production value (here the lot size valued at market prices) amounts to € 3698. Following traditional cost accounting, the identification of all production value and value-consumption types of the company and the distribution to quantity units and process was carried out by means of a cost allocation sheet. Table 3 summarizes the value consumption of the different production types per order.

Table 3. Value consumption of the internal system per order depending on the production type.

	Ablative	Additive
Direct material costs	132.00 €	70.98 €
Material overheads	320.36 €	172.27 €
Wages, salaries, social costs, boni	1173.50 €	1647.02 €
Production overheads	455.32 €	639.04 €
Administrative and selling overheads	116.18 €	163.06 €
Special direct manufacturing costs	12.40 €	0.00 €
Total	2209.76 €	2692.37 €

For the ablative production of the examined order, the IWS amounts to 1488.24 €. In the case of additive manufacturing, this amounts to 1005.63 €. Since no benefit contribution to the external system in terms of the e^2VA can be invoiced here, there is only a reduction in natural value. In the case of ablative manufacturing, this amounts to 36.96 € for the entire order, and 64.53 € if additive manufacturing is used. Correspondingly, the e^2VA of the traditional production amounts to 1451.28 €. In contrast, generative manufacturing has an e^2VA of 941.1 €. Figure 4 illustrates the comparison of the two manufacturing methods.

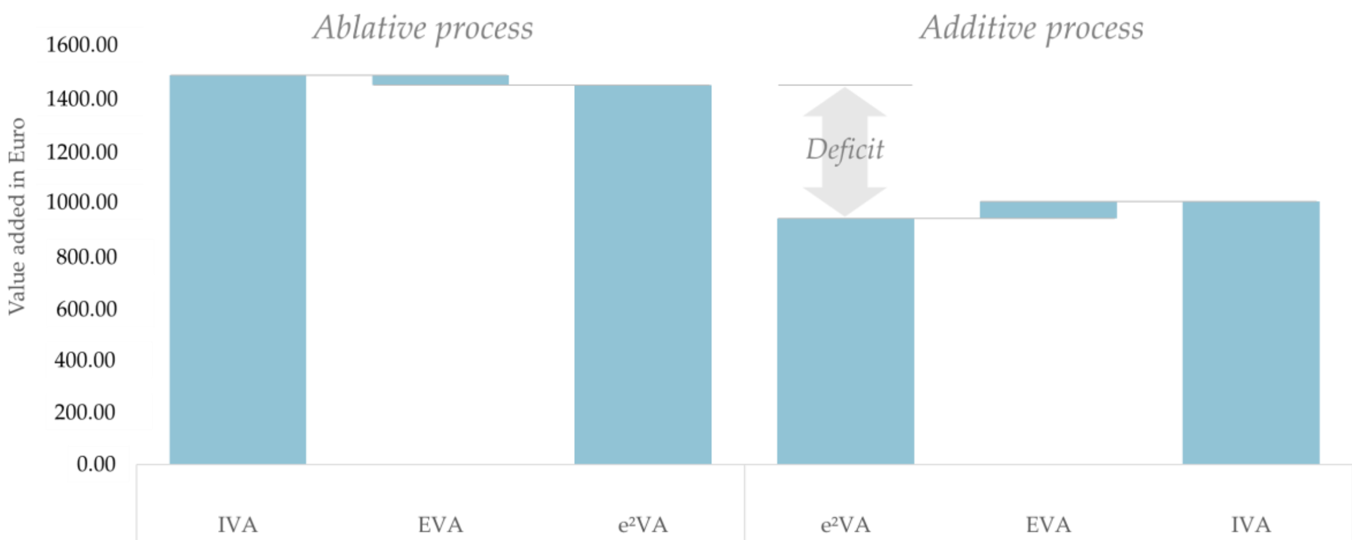

Figure 4. e^2VA comparison of order process via ablative and additive manufacturing.

The value-added deficit in contract manufacturing using the additive process amounts to € 510.18. Since the externality condition is not met in both cases, the processes are classified as unsustainable. The capital transfer of both process alternatives is not legitimized in terms of sustainability, although the ablative manufacturing has clear advantages with regard to the use of the external system. The sustainability deficit of the erosive production amounts to about 0.02. To ensure sustainable value creation, 2 cents per € economic value generated would have to be paid as a benefit contribution in the sense of the e^2VA calculation. In the case of additive production, there is a sustainability deficit of around 0.06. The generative example process analyzed here is also inferior with regard to the reduction in natural value. In the case of a court settlement, the consideration of these dynamics is of essential importance for the preparation of the decision. In this case, this was calculated for the lot size interval [1; 400], assuming a graduated price depending on the sales quantity. It becomes clear that the generative manufacturing process for small lot sizes (LS $\leq$ 17) has advantages in terms of e^2VA calculation compared to the ablative manufacturing. With increasing output quantity (LS > 17), however, this is to be preferred. With regard to the reduction in natural value, the ablative process is superior at all times, although the average reduction is significantly higher with increasing quantities in the case of generative manufacturing. This is due to the small number of auxiliary materials and supplies used (excluding electricity) and production waste. Figure 5 illustrates the dynamics of e^2VA and natural degradation as a function of production type and batch size.

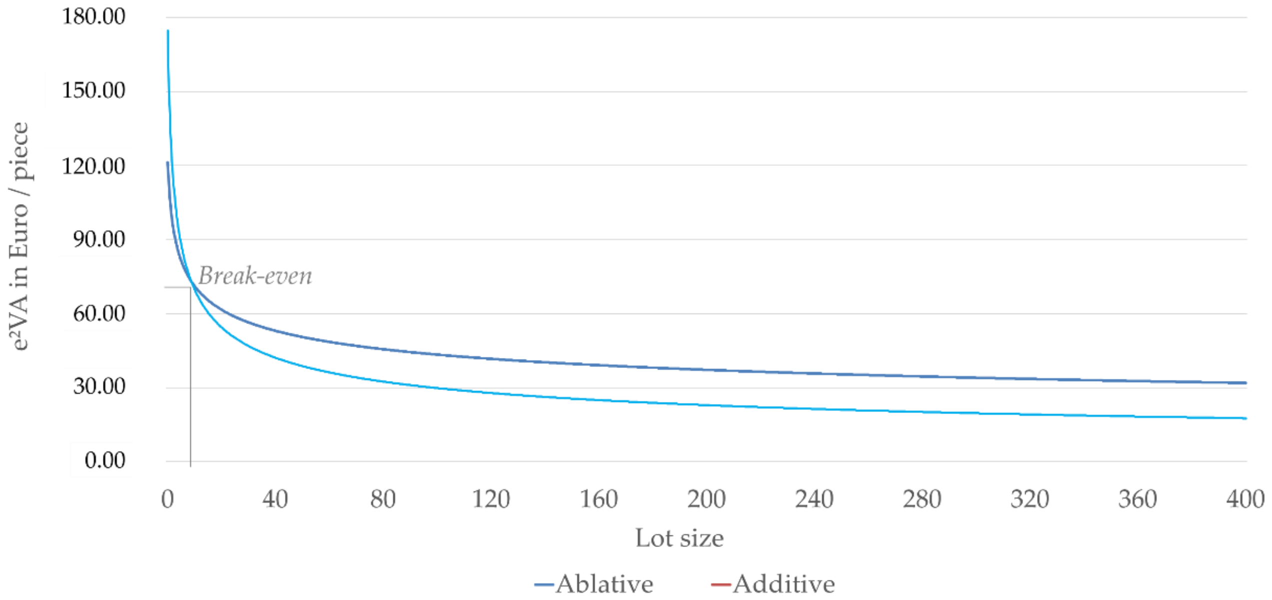

Figure 5. Dynamics of e^2VA and external value reduction as a function of production type and batch size.

Both application examples do not fulfil the externality condition and must therefore both be classified as illegitimate actions in the context of sustainability. Apart from very small batch sizes, the ablative production is to be preferred from both perspectives economic and environmental. The examples also make it clear that a selective evaluation of individual technologies with regard to their environmental impact is not reasonable, since the use of a completely new technology is generally not possible independent of existing structures. Frequently, when embedding in an existing production system, as shown here in the example of generative manufacturing, a combination with existing technologies is necessary. Although the FDM process that was chosen here is hardly suitable for industrial application due to the processability of the basic material POM, the comparison nevertheless highlights a significant deficit in the additive manufacturing processes that are available today: the duration of processing.

4. Conclusions

The term sustainable value creation is currently a common dictum in science and practice. Although the sustainability baseline concept has been around for over 40 years, its operationalization to business value-added calculation is rare. While integration of sustainability into business management is now common practice in companies, its results rarely lead to decisions that are appropriate in the sense of a regulative economy. In this paper, we thus raised the question of what exactly the 'value-added of production' from an economic and ecological perspective is. We analyzed to what extent current theories and concepts of (business) economics reflect the question of an integrated under-standing of value and how an integrated value-added accounting system should be designed. We introduced a novel accounting system that combines elements of traditional operational value-added accounting, process and material flow analysis as well as LCA. The method is based on an extended system thinking, a set of principles, a calculation system, and external cost factors for the impact categories climate change, stratospheric ozone depletion, air pollution, eutrophication and acidification. The approach is validated in two application examples in the German special tools industry, proving its practicability and reproducibility as well as the suitability of specifically derived indicators for the selective optimization of production systems.

The concept allows for the quantification of an objectified value-added of production systems with regard to socially perceived environmental problems. However, its advantages over previous approaches are counterbalanced by isolated potentials that can be exploited in the future through further research and development. These are essentially rooted in the objectives of the chosen terminology, the validity of the assumptions made and the loss or deficit of information. First of all, the aim of the approach, i.e., to determine an objective value-added, is inherently problematic. Since the perception of value as such is always based on an individual human judgement, the subjectivity of value creation can never be completely excluded. From an anthropocentric perspective, the objectification of the concept of value can only take place via iterative approximation towards a balance, society strives for. A further goal of the present approach is to completely avoid perceived environmental problems and to realize the associated effective self-sufficient action. Last but not least, the loss of information and information deficits when expanding the balance sheet framework lead to increased uncertainty. One reason for this is the monetization of external effects, regardless of the chosen procedure. A complete quantification of all external effects of an action is not possible, due to the loss of information in the external system.

Although its quantification is associated with considerable uncertainties, it is urgently required for operational decision-making. In the future, the approach can be applied in manufacturing companies in a self-determined way, with the main purpose of resolving the economic–ecological conflict of objectives by broadening the perspective and anticipating future risks with regard to environmental regulatory developments. For an independent use, however, most/many producing companies currently lack transparency about the physical consumption and upstream supply chains. To achieve this, companies and political institutions will need to increase their efforts to digitize processes, facilities and overcome the current barriers of supply chain communication. Equally conceivable is the use of the procedure as a basis for environmental regulatory measures, e.g., eco-tax or eco-labels. Applying the method in this way would have several political implications. For example, it would be necessary to designate a legitimized entity to determine the external procurement prices in order to ensure comparability along the value chain. Simultaneously, companies would have to be obliged to report the indicator 'sustainable value-added' in their annual financial statements, which, in turn, could have implications for the granting of loans. Banks' lending conditions, could be based not only on economic performance, but also on environmental performance. The most promising use, however, would be for the calculation of necessary holistic compensation services or simply for the evaluation of offers for such services by compensation service providers. However, suc deployment requires regulatory mandates or a shift in customer needs toward more sustainable, transparent products.

In any case, the concept would benefit from a number of adaptations that could not be carried out in the present work. First, the socio-economic analysis to be carried out by a company under its own responsibility increases the subjectivity of the indicator. A further objectification can be achieved solely by the designation of a socially accepted authority, into whose responsibility the constant follow-up and classification of the perceived environmental problem fields, the standardized calculation of the procurement prices, and a standardization of the procedure and regular audits fall. Social diffusion, documented by the media presence of an environmental problem, can be used as an indicator of constant tracking and updating. In this context, research and development work should be intensified in the future. Further insight is needed for the construction of the impact chains of perceived environmental problems, the leveling of the overlap of external effects of different categories, the extension of the modeling to further environmental problem fields and the integration into real-time capable information and communication technologies.

In addition, extending supply-chain communication via IT support is needed. Improving the data basis of the background system is essential, especially for ecology-oriented decision-making in companies (e.g., make-or-buy, supplier selection). On the basis of the rapid technological development in the field of information and communication technology regarding the measurement and control instruments, a significant improvement in the data availability regarding external effects is to be expected in the future. A real-time evaluation of the subsequent value creation would also be conceivable in this context. Nevertheless, concepts that exists at present are at least partially effective here (including SAP Product Stewardship Network, HP CDX, GaBi, Umberto NXT LCA). However, the need to provide data, some of which are critical to success (e.g., chemical composition), to third parties often proves problematic. Communication based on a purely pecuniary indicator would greatly simplify the transfer of information. Figure 6 illustrates a rather simple communication concept based on the eco^2 value-added calculation.

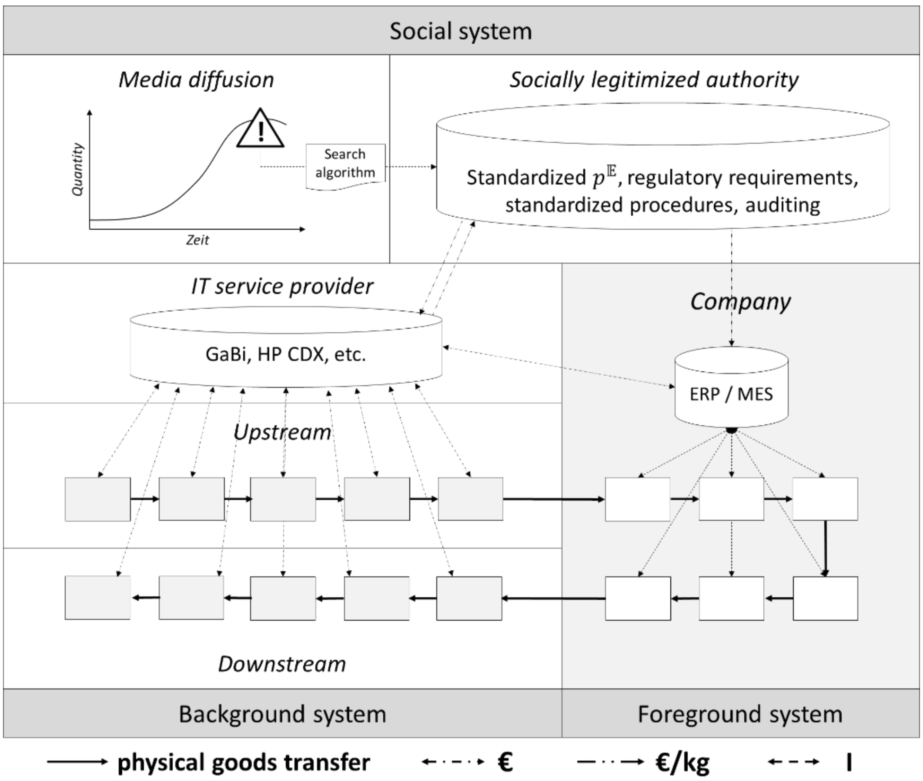

Figure 6. Normative-informative implementation of the eco^2 value-added calculation within the supply chain.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su142013603/s1. Premises of an integrated value added accounting; input-output balances of case studies; approach, reference indicators and basic assumptions of $p^{\mathbb{E}}$ calculation.

Author Contributions: Conceptualization, R.M.; Formal analysis, R.M.; Investigation, R.M.; Methodology, R.M.; Supervision, M.F., A.S. and T.B.; Validation, R.M.; Visualization, R.M.; Writing—original draft, R.M.; Writing—review & editing, M.F., A.S. and T.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. All necessary information can be found in supporting materials.

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

References

1. World Commission on Environment and Development. Our Common Future: Report of the World Commission on Environment and Development. United Nations. Available online: www.un-documents.net/our-common-future.pdf (accessed on 25 August 2022).
2. Ayres, R.; Van den Berrgh, J.; Gowdy, J. Strong versus weak sustainability: Economics, natural sciences, and consilience. *Environ. Ethics* **2001**, *23*, 155–168. [CrossRef]
3. Daly, H.E. Sustainable Development: From Concept and Theory to Operational Principles. *Popul. Dev. Rev.* **1990**, *16*, 25–43. [CrossRef]
4. Dedeurwaerdere, T. *Sustainability Science for Strong Sustainability*; Edward Elgar Publishing: Cheltenham, UK, 2014; p. 174.
5. Bonnedahl, K.J.; Heikkurinen, P. The case for strong sustainability. In *Strongly Sustainable Societies*; Routledge: London, UK, 2018; pp. 1–20.
6. Landrum, N.E. Stages of corporate sustainability: Integrating the strong sustainability worldview. *Organ. Environ.* **2018**, *31*, 287–313. [CrossRef]
7. Olausson, H. A Tool for Calculating CO_2 Emissions in the Manufacturing Industry: Use of GHG Protocol. 2020. Available online: http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1446855&dswid=-431 (accessed on 25 August 2022).
8. Bansal, S.; Garg, I.; Sharma, G.D. Social entrepreneurship as a path for social change and driver of sustainable development: A systematic review and research agenda. *Sustainability* **2019**, *11*, 1091. [CrossRef]
9. Schaltegger, S.; Gibassier, D.; Zvezdov, D. Is environmental management accounting a discipline? A bibliometric literature review. *Meditari Account. Res.* **2013**, *21*, 4–31. [CrossRef]
10. Thomson, I. Mapping the terrain of sustainability accounting. In *Sustainability Accounting and Accountability*; Routledge: London, UK, 2010; pp. 38–55.
11. McGrath, D.; Mathews, M. Moving to sustainability: An application of a matrix model to gain insight into the research literature. *Account. Account. Perform.* **2008**, *14*, 57–81.
12. Gunarathne, N.; Lee, K.H. Environmental Management Accounting (EMA) for environmental management and organizational change: An eco-control approach. *J. Account. Organ. Change* **2015**, *11*. [CrossRef]
13. Asiedu, Y.; Gu, P. Product life cycle cost analysis: State of the art review. *Int. J. Prod. Res.* **1998**, *36*, 883–908. [CrossRef]
14. Jamwal, A.; Agrawal, R.; Sharma, M. Life cycle engineering: Past, present, and future. In *Sustainable Manufacturing*; Elsevier: Amsterdam, The Netherlands, 2021; pp. 313–338.
15. Nathaniel, S.; Nwodo, O.; Sharma, G.; Shah, M. Renewable energy, urbanization, and ecological footprint linkage in CIVETS. *Environ. Sci. Pollut. Res.* **2020**, *27*, 19616–19629. [CrossRef]
16. *ISO 14040:2006*; Environmental Management—Life Cycle Assessment—Principles and Framework. ISO: Geneva, Switzerland, 2006.
17. *ISO 14044:2006*; Environmental Management—Life Cycle Assessment—Requirements and Guidelines. ISO: Geneva, Switzerland, 2006.
18. Ulrich, P.; Hill, W. Wissenschaftstheoretische Grundlagen der Betriebswirtschaftslehre—Teil I. *Wirtsch. Stud. Z. Ausbild. Hochschulkontakt* **1976**, *5*, 304–309.
19. Waltersmann, L.; Kiemel, S.; Stuhlsatz, J.; Sauer, A.; Miehe, R. Artificial Intelligence Applications for Increasing Resource Efficiency in Manufacturing Companies—A Comprehensive Review. *Sustainability* **2021**, *13*, 6689. [CrossRef]
20. Miehe, R.; Buckreus, L.; Kiemel, S.; Sauer, A.; Bauernhansl, T. A Conceptual Framework for Biointelligent Production—Calling for Systemic Life Cycle Thinking in Cellular Units. *Clean Technol.* **2021**, *3*, 844–857. [CrossRef]
21. Harari, Y.N. *Sapiens: A Brief History of Humankind*; Harper: New York City, NY, USA, 2016; ISBN 978–0062316097.

22. Kant, I.; Schneewind, J.B. *Groundwork for the Metaphysics of Morals*; Yale University Press: New Haven, CT, USA, 2002; ISBN 978–1107401068.
23. Ulrich, P. *Integrative Wirtschaftsethik: Grundlagen einer lebensdienlichen Ökonomie*; Haupt: Bern, Switzerland, 2008; ISBN 978–3258072616.
24. Hornborg, A. Ecological economics, Marxism, and technological progress: Some explorations of the conceptual foundations of theories of ecologically unequal exchange. *Ecol. Econ.* **2014**, *105*, 11–18. [CrossRef]
25. Smith, A. *The Wealth of Nations: An Inquiry into the Nature and Causes of the Wealth of Nations*; Oxford University Press: Oxford, UK, 2008; ISBN 978–0199535927.
26. Ricardo, D. From the principles of political economy and taxation. In *Readings in the Economics of the Division of Labor: The Classical Tradition*; Sun, G.-Z., Ed.; World Scientific Pub. Co. Inc.: Singapore, 2005; pp. 127–130. ISBN 978–9812561244.
27. Marx, K. *Capital: Volume 1: A Critique of Political Economy*; CreateSpace Independent Publishing Platform: Scotts Valley, SC, USA, 2014; ISBN 978–1499236316.
28. von Thünen, J.H. *Der Isolirte Staat in Beziehung auf Landwirthschaft und Nationalökonomie*; Scientia: Amsterdam, The Netherlands, 1990; ISBN 3511092183.
29. Jevons, W.S. *Coal Question*; Augustus M Kelley Pubs: New York, NY, USA, 1906; ISBN 978–0678001073.
30. Menger, C. *Grundsätze der Volkswirtschaftslehre*; VDM: Saarbrücken, Germany, 2006; ISBN 3865505236.
31. Walras, L. *Elements of Pure Economics: Or the Theory of Social Wealth*; Routledge Chapman & Hall: New York, NY, USA, 2003; ISBN 978–0415313407.
32. Kapp, K.W. *The Social Costs of Private Enterprise*; Schocken Books: New York, NY, USA, 1971; ISBN 978-0805233964.
33. Costanza, R.; d'Arge, R.; De Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Van Den Belt, M. The value of the world's ecosystem services and natural capital. *Nature* **1997**, *387*, 253–260. [CrossRef]
34. Socolow, R.; Andrews, C.; Berkhout, F.; Thomas, V. *Industrial Ecology and Global Change*; Cambridge University Press: Cambridge, UK, 1994; ISBN 0521471974.
35. Bartelmus, P. Environmental accounting and material flow analysis. In *A Handbook of Industrial Ecology*; Ayres, R.U., Ayres, L.W., Eds.; Edward Elgar Publishing Inc.: Northampton, MA, USA, 2002; pp. 165–176. ISBN 1840645067.
36. Burkett, P. The value problem in ecological economics: Lessons from the physiocrats and Marx. *Organ. Environ.* **2003**, *16*, 137–167. [CrossRef]
37. De Chernatony, L.; Harris, F.; Dall'Olmo Riley, F. Added value: Its nature, roles and sustainability. *Eur. J. Marketing.* **2000**, *34*, 39–56. [CrossRef]
38. Rasmussen, S. *Production Economics: The Basic Theory of Production Optimization*; Springer Science & Business Media: Berlin, Germany, 2012; ISBN 978–3642301995.
39. Beattie, B.R. *The Economics of Production*; McGraw-Hill: New York, NY, USA, 2009; ISBN 978–1575242958.
40. Westkämper, E. *Einführung in Die Organisation der Produktion*; Springer: Berlin, Germany, 2006; ISBN 3540260390.
41. Zahn, E.; Schmidt, U. *Produktionswirtschaft—Band 1: Grundlagen und Operatives Produktionsmanagement*; UTB: Stuttgart, Germany, 1996; ISBN 978–3-8252–8126–7.
42. Porter, M.E. The value chain and competitive advantage. In *Understanding Business Processes*; Psychology Press: Brighton, UK, 2001; pp. 50–66.
43. Womack, J.P.; Jones, D.T.; Roos, D. *The Machine That Changed the World: The Story of Lean Production—Toyota's Secret Weapon in the Global Car Wars That Is Now Revolutionizing World Industry*; Free Press: New York, NY, USA, 2007.
44. Zeithaml, V.A. Consumer perceptions of price, quality, and value: A means-end model of synthesis of evidence. *J. Mark.* **1988**, *52*, 2–22. [CrossRef]
45. Herrmann, C.; Blume, S.; Kurle, D.; Schmidt, C.; Thiede, S. The positive impact factory–transition from eco-efficiency to eco–effectiveness strategies in manufacturing. *Procedia Cirp* **2015**, *29*, 19–27. [CrossRef]
46. Miehe, R.; Stender, S.; Hessberger, N.; Mandel, J.; Sauer, A. Improving manufacturing systems with regard to the concept of ultra-efficiency. In *Advances in Manufacturing Technology XXXI*; IOS Press: Amsterdam, The Netherlands, 2017; pp. 321–326.
47. Lazdinis, M. Measuring economic value of biological diversity: Concepts, theories and methods. *Balt. For.* **2001**, *7*, 84–89.
48. Sagoff, M. On the economic value of ecosystem services. *Environ. Values* **2008**, *17*, 239–257. [CrossRef]
49. Mehvar, S.; Filatova, T.; Dastgheib, A.; De Ruyter van Steveninck, E.; Ranasinghe, R. Quantifying economic value of coastal ecosystem services: A review. *J. Mar. Sci. Eng.* **2018**, *6*, 5. [CrossRef]
50. Rockström, J.; Steffen, W.; Noone, K.; Persson, Å.; Chapin, F.S., III; Lambin, E.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.; et al. Planetary boundaries: Exploring the safe operating space for humanity. *Ecol. Soc.* **2009**, *14*, 32. [CrossRef]
51. Krol, G.J.; Karpe, J. *Ökonomische Aspekte von Nachhaltigkeit: Die Umweltproblematik aus Sozioökonomischer Sicht*; LIT: Münster, Germany, 1999; ISBN 978–3825844103.
52. Klöpffer, W.; Grahl, B. *Life Cycle Assessment (LCA): A Guide to Best Practice*; John Wiley & Sons: Hoboken, NJ, USA, 2014.
53. Koedel, C.; Rockoff, J.E. Value-added modeling: A review. *Econ. Educ. Rev.* **2015**, *47*, 180–195. [CrossRef]
54. Fedorovich, V.O.; Fedorovich, T.V. Corporate business value: Asymmetric information in the calculation of economic value added. *Finan. Anal. Probl. Solut.* **2019**, *2*, 183–203. [CrossRef]

55. Wu, N.; Rao, Q. Enterprise value evaluation: Application and improvement based on cash flow model and Economic Value Added model. In *2017 International Conference on Humanities Science, Management and Education Technology (HSMET 2017)*; Atlantis Press: Berlin, Germany, 2017; pp. 185–190.
56. Jakub, S.; Viera, B.; Eva, K. Economic Value Added as a measurement tool of financial performance. *Procedia Econ. Financ.* **2015**, *26*, 484–489. [CrossRef]
57. Miehe, R. *Methodik zur Quantifizierung der Nachhaltigen Wertschöpfung von Produktionssystemen an der öKonomisch-ökologischen Schnittstelle Anhand Ausgewählter Umweltprobleme*; Fraunhofer Verlag: Stuttgart, Germany, 2018.
58. Bebbington, J.; Gray, R.; Hibbitt, C.; Kirk, E. *Full Cost Accounting: An Agenda for Action*; ACCA Research Report: London, UK, 2001.
59. Birkin, F. Ecological accounting: New tools for a sustainable culture. *Int. J. Sustain. Dev. World Ecol.* **2003**, *10*, 49–61. [CrossRef]
60. Egan, M. Making water count: Water accountability change within an Australian university. *Account. Audit. Account. J.* **2014**, *27*, 259–282. [CrossRef]
61. Hazelton, J. Accounting as a human right: The case of water information. *Account. Audit. Account. J.* **2013**, *26*, 267–311. [CrossRef]
62. Samkin, G.; Schneider, A.; Tappin, D. Developing a reporting and evaluation framework for biodiversity. *Account. Audit. Account. J.* **2014**, *27*, 527–562. [CrossRef]
63. Tello, E.; Hazelton, J.; Cummings, L. Potential users' perceptions of general purpose water accounting reports. *Account. Audit. Account. J.* **2016**, *29*, 80–110. [CrossRef]
64. Russell, S.; Milne, M.J.; Dey, C. Accounts of nature and the nature of accounts: Critical reflections on environmental accounting and propositions for ecologically informed accounting. *Account. Audit. Account. J.* **2017**, *30*, 1426–1458. [CrossRef]
65. Plagiannakos, T. Full Cost Accounting for Decision Making at Ontario Hydro. *IPPSO Facto* **1996**, *10*, 22–23.
66. Jasch, C. *Environmental and Material Flow Cost Accounting: Principles and Procedures*; Springer: Berlin, Germany, 2009; ISBN 978–1402090271.
67. Burritt, R.L.; Schaltegger, S.; Ferreira, A.; Moulang, C.; Hendro, B. Environmental management accounting and innovation: An exploratory analysis. *Account. Audit. Account. J.* **2010**. Available online: https://www.emerald.com/insight/content/doi/10.1108/09513571011080180/full/html (accessed on 25 August 2022).
68. Burritt, R.L. Environmental management accounting: Roadblocks on the way to the green and pleasant land. *Bus. Strategy Environ.* **2004**, *13*, 13–32. [CrossRef]
69. Mathews, M.R.; Lockhart, J.A. *The Use of an Environmental Equity Account to Internalise Externalities*; Aston Business School Research Institute: Birmingham, UK, 2001; ISBN 1854495119.
70. Cullen, D.; Whelan, C. Environmental management accounting: The state of play. *J. Bus. Econ. Res.* **2006**, *4*. [CrossRef]
71. Bartolomeo, M.; Bennett, M.; Bouma, J.J.; Heydkamp, P.; James, P.; Wolters, T. Environmental management accounting in Europe: Current practice and future potential. *Eur. Account. Rev.* **2000**, *9*, 31–52. [CrossRef]
72. Kesicki, F.; Ekins, P. Marginal abatement cost curves: A call for caution. *Clim. Policy* **2012**, *12*, 219–236. [CrossRef]
73. Ward, D.J. The failure of marginal abatement cost curves in optimising a transition to a low carbon energy supply. *Energy Policy* **2014**, *74*, 820–822. [CrossRef]
74. Sukhdev, P.; Wittmer, H.; Schröter-Schlaack, C.; Nesshöver, C.; Bishop, J.; ten Brink, P.; Gundimeda, H.; Kumar, P.; Simmons, B. *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB*; UNEP: Geneva, Switzerland, 2010.
75. Helm, D. *Natural Capital: Valuing the Planet*; Yale University Press: New Haven, CT, USA, 2015.
76. Juniper, T. *What Has Nature Ever Done for Us?: How Money Really Does Grow on Trees*; Synergetic Press: London, UK, 2013.
77. CIMA. Accounting for Natural Capital: The Elephant in the Boardroom. Available online: www.cimaglobal.com/Documents/Thought_leadership_docs/Sustainability%20and%20Climate%20Change/CIMA-accounting-for-natural-capital.pdf (accessed on 25 August 2022).
78. Trucost. Available online: www.trucost.com/ (accessed on 25 August 2022).
79. Eftec. Economics for the Environment Consultancy. Available online: www.eftec.co.uk/ (accessed on 25 August 2022).
80. Hunkeler, D.; Lichtenvort, K.; Rebitzer, G. *Environmental Life Cycle Costing*; Taylor & Francis Inc.: Milton Park, UK, 2008; ISBN 978–1420054705.
81. Vogtländer, J.G.; Bijma, A. The 'Virtual Pollution Prevention Costs ′99'. *Int. J. Life Cycle Assess.* **2000**, *5*, 113–124. [CrossRef]
82. Vogtländer, J.G.; Brezet, H.C.; Hendriks, C.F. The Virtual Eco-Costs ′99. *Int. J. Life Cycle Assess.* **2001**, *6*, 157–166. [CrossRef]
83. Figge, F.; Hahn, T. *Sustainable Value Added: Measuring Corporate Sustainable Performance beyond Eco-Efficiency*; Universität Lüneburg: Lüneburg, Germany, 2002; ISBN 978–3935630191.
84. Burschel, C.J.; Losen, D.; Wiendl, A. *Betriebswirtschaftslehre der Nachhaltigen Unternehmung*; Oldenbourg Wissenschaftsverlag: München, Germany, 2004; ISBN 978–3486200331.
85. KPMG/ACCA. Natural Capital and the Accountancy Profession. Available online: www.accaglobal.com/content/dam/ACCA_Global/Technical/sus/NC_and_the_Accounting_Profession.pdf (accessed on 25 August 2022).
86. Umweltbundesamt. Ökonomische Bewertung von Umweltschäden: Methodenkonvention 2.0 zur Schätzung von Umweltkosten. Dessau-Roßlau. Available online: http://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/uba_methodenkonvention_2.0_-_2012_gesamt.pdf (accessed on 25 August 2022).

87. European Commission (Ed.) *International Reference Life Cycle Data System (ILCD) Handbook: General Guide for Life Cycle Assessment—Detailed Guidance*; Publications Office of the European Union: Luxembourg, 2010; ISBN 978-9279190926.
88. Zhu, Z.; Piao, S.; Myneni, R.B.; Huang, M.; Zeng, Z.; Canadell, J.G.; Ciais, P.; Sitch, S.; Friedlingstein, P.; Arneth, A.; et al. Greening of the Earth and its drivers. *Nat. Clim. Change* **2016**, *6*, 791–795. [CrossRef]
89. Chandra, J.; Schall, S.O. Economic justification of flexible manufacturing systems using the Leontief input-output model. *Eng. Econ.* **1988**, *34*, 27–50. [CrossRef]
90. Heijungs, R. *Environmental Life Cycle Assessment of Products*; Multicopy: Leiden, The Netherlands, 1992; ISBN 90-5191-064-9.
91. Umweltbundesamt. Prozessorientierte Basisdaten für Umweltmanagementsysteme. Dessau-Roßlau. Available online: www.probas.umweltbundesamt.de (accessed on 25 August 2022).