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Designing and Testing a Tool that Connects the Value Proposition of Deep-Tech Ventures to SDGs

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Abstract: Deep-tech startups have enormous potential to solve major societal challenges, but their failure rates are quite high (above 90%). In this respect, deep-tech systems and products have long development times and thus require substantial amounts of investment capital long before the first customer can be served. Moreover, potential investors increasingly expect that the value proposition of a deep-tech venture has a clear sustainability dimension. We therefore designed a tool that serves to develop a convincing value proposition for investors, one that is explicitly connected to the Sustainable Development Goals (SDGs) of the United Nations. We adopted a design science approach to develop and test this tool in the context of a deep-tech venture builder located in the Netherlands. The final tool arising from this study extends and integrates various existing tools with an explicit connection to the SDGs. As such, this tool enables deep-tech entrepreneurs to develop a value proposition that is more likely to attract early-stage investors.

Keywords: value proposition; entrepreneurship; deep-tech; venturing; sustainability; SDGs; investors; investment capital; theory of change; design science

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1. Introduction

Deep-tech systems and products are disruptive solutions that arise from unique, hard-to-reproduce scientific or technological advances [1] and often address big societal challenges [2]. As such, deep-tech startups seek to commercialize products that integrate extremely complex software with novel hardware [3]. Deep-tech products are typically bought by industrial customers on business-to-business (B2B) markets [3]. The high potential returns of deep-tech ventures come with high market as well as technology risks, as argued by Portincaso et al. [2] who compare deep-tech to Software as a Service (SaaS) and biotech. Compared to SaaS ventures, which suffer only from market risk, building a minimum viable product is far more expensive for deep-tech products and they are also less easily scalable [2]. Similarly, biotech ventures face high technological risks but also have a low market risk compared to deep-tech. In this respect, biotech ventures follow a more traditional product development process, such as clinical trial gates, while deep-tech does not allow for this type of process [2]. Finally, deep-tech usually involves rather long investment horizons (of 10 to 20 years) before the investor can make an exit [2]. The failure rate of deep-tech ventures is thus 90% or higher [3].

This implies the so-called "valley of death", the period in which the technology has left the lab but is not yet commercially available, is extremely long and deep in the case of deep-tech ventures. In terms of Technology Readiness Levels [4], the valley of death in deep-tech ranges from TRL 3 to TRL 7 [3]. This huge valley of death makes it all the more important for deep-tech entrepreneurs to formulate and communicate the value proposition of their venture to early-stage investors [2]. Yet, at the same time, it is also extremely challenging to do so [5]. Early-stage investors typically need to invest heavily in a deep-

tech venture long before the first customer can be served. In this respect, early-stage deep-tech ventures do not yet have a client base, which implies that investors cannot validate the venture's value proposition directly [6].

Moreover, potential early-stage investors are increasingly expecting that the value proposition of a deep-tech venture has a clear sustainability dimension [3]. Deep-tech ventures, therefore, need to generate significant environmental and/or societal value [2]. The17 Sustainable Development Goals (SDGs), formulated "to transform our world and to improve people's lives and prosperity on a healthy planet" [7], provide an interesting framework in this area. SDG impact investing is thus a rapidly growing phenomenon, increasing from 16 billion euros in 2020 to 39 billion euros in 2021 globally [8]. However, deep-tech entrepreneurs often fail to develop an articulated 'impact' narrative, resulting in a lack of understanding by investors [2].

Thus, the core problem addressed in this study is that early-stage deep-tech entrepreneurs are facing a long and deep valley of death, in which they need to (a) convince investors to allocate substantial amounts of capital long before the first customer can be served and (b) include a clear sustainability dimension in their venture's value proposition. A tool that addresses this combined challenge is not yet available in the literature. Therefore, we seek to design and test a tool that helps deep-tech entrepreneurs more effectively communicate their venture's value proposition to investors, by including a clear connection to (at least one of) the SDGs in this value proposition. We conducted this research within HighTechXL, a deep-tech venture builder located in the Netherlands, using a design science approach [9,10]. The main contribution of this study is a tool that deep-tech entrepreneurs can use to develop sustainable value propositions that effectively convince early-stage investors.

The next section describes the theoretical background of this study. Subsequently, we describe how the tool was designed and tested. The Discussion section then serves to evaluate the main findings.

2. Background

2.1. Existing Value Proposition Tools

Osterwalder et al. [11] (p. 43) defined a value proposition as "an overall view of a company's bundle of products and services that are of value to the customer." This definition can be broadened by arguing that a value proposition should also consider other stakeholders and interests such as the natural environment and society at large [12,13]. This broadened definition is especially applicable to deep-tech ventures, because these are strongly associated with solving SDGs [2]. Therefore, the value created for the environment and society is essential in a deep-tech venture's value proposition. We therefore define a value proposition as a statement that depicts how (a bundle of) products and services create(s) value for the customer and impacts other societal and environmental stakeholders.

A company's products and services are at the core of its value proposition. However, a deep-tech venture often does not yet have a product or service of value to any customers. Therefore, other methods for communicating the venture's proposed value proposition have to be utilized in attracting investors. These methods can be divided into three categories: semantic, tangible, and visual methods. *Semantic* methods are essential for deep-tech ventures, because these ventures tend to lack an articulated narrative due to the nascent and complex nature of their products [2]. Moreover, 81% of deep-tech entrepreneurs believe that "investors, on average, lack scientific/engineering expertise to assess deep-tech potential" [2] (p. 13). To decrease the lack of understanding among investors, deep-tech ventures need to know 'what' should be communicated and 'how' it should be communicated to be understandable for investors. Existing tools for developing and communicating the semantic side of a value proposition include the tools of Straker and Nusem [14] and Straker and Wrigley [15], which can help better articulate the 'what' and

'why' of any value proposition. The tool developed by Beckett [16] focuses on what to include when a value proposition is pitched to an audience.

Because deep-tech products by definition have a substantial (often novel) hardware component, communicating the value proposition of a deep-tech venture through *tangibles* is equally essential. In this respect, the development of tangible prototypes appears to be one of the main drivers for successful product development [17]. Moreover, prototypes appear to be key tangibles in the early stages of collaborating with investors and other stakeholders, which in turn increases the likelihood of venture success [18]. As observed in Section 1, deep-tech products require high levels of skill, major investments, and long-development times [1,2,19], which results in a long and deep valley of death [3]. It is therefore critical for deep-tech ventures to keep the development time and development costs as short and low as possible. In this respect, the Design-Build-Test-Learn cycle for deep-tech ventures adapts the Lean startup methodology to deep-tech, in order to bring together multi-disciplinary teams that accelerate problem solving; this results in continuous learning, reducing the time-to-market, de-risking, and improved customer-product fit [2]. Another method is a makerspace, a shared facility in which ventures gain access to otherwise unaffordable equipment for a limited fee [20]. A makerspace allows prototypes and value propositions to be quickly developed and tested [11,20].

Regarding *visual* methods, a well-known tool is the Value Proposition Canvas [11]. The Value Proposition Canvas (VPC) is part of the Business Model Canvas, both of which have become widely used [21]. The VPC focuses on gaining an understanding of the customer (segment) through the 'customer profile' and developing a corresponding value proposition in the 'value map'. However, the VPC does not incorporate other desirable impacts, such as the value proposition's effect on society and environment—as advocated elsewhere [12,22–25]. Several other tools do address the sustainability dimension of value propositions. For example, the so-called Theory of Change (ToC) framework serves to uncover the mental representations and theoretical assumptions that explain how a new initiative (e.g., ventures, projects, programs) may generate particular changes [26]. As such, the ToC tool is already being used by entrepreneurs and investors [27]. Section 4.1 will describe the ToC in more detail.

A tool that focuses on developing sustainable value propositions is the value mapping tool for sustainable business modeling [22]. This tool was created to help a company balance the economic, social, and environmental value in its value proposition, but is mainly applicable to the ideation and analysis stages [25]. Vladimirova [25] therefore proposed a complementary tool that serves to build sustainable value propositions; this tool is based on multiple literature streams, combining the concepts of value proposition [11], sustainable value [28], sustainable business models [22], and mutuality and reciprocity of stakeholders in a broader societal and environmental setting [29]. The final design of this tool incorporates various stakeholders and guides the user in defining the economic, social, and environmental value for each stakeholder. However, it does not include an explicit opportunity to connect these values to the SDGs, a framework often used by deep-tech ventures and investors (see Section 2.2).

In sum, the various tools discussed in this section do not provide a complete instrument for effective communication of a deep-tech venture's sustainability-oriented value proposition to investors.

2.2. Communicating with Investors

The early stages of deep-tech ventures are extremely capital-intensive, due to the long time-to-market and their highly complex hardware-based solutions [3]. The uncertainty about (any) future return on investment is thus exceptionally high [30]. Attracting external investors is therefore extremely critical but also rather challenging for any deep-tech venture in its early stages.

Moreover, early stage deep-tech ventures especially give rise to substantial levels of information asymmetry between the venture team and the investor; that is, the former

possesses more knowledge about the venture than the latter [6,31]. For example, venture team members have much more information about their competencies and the actual usage of any investment capital [32]. In addition, the required information can be difficult to gather or does not (yet) exist at all [33], also because the main assets of early-stage ventures are intangible in nature (e.g., expertise), which makes it hard for potential investors to directly assess these assets [31].

The literature on signaling theory serves to study investor communication of (early-stage) ventures in a more detailed manner [31,34–36]. Central to this theory is how sending (positive) signals to external parties can decrease information asymmetry. This decreased information asymmetry can potentially enhance the likelihood of receiving investments from an external investor [31,37]. Moreover, Audretsch et al. [31] found that combining multiple signals can have a greater effect than the sum of the individual signals. Examples of these signals include filed patents, working prototypes, committed team members, and demonstrated potential for scalability with high imitation barriers [38–41].

Another aspect of a venture's value proposition is the intended societal impact. The growing importance of the impact dimension for investors is visible in the total volume of impact investments, which is estimated to be around 40 billion euros per year [8]. In addition, the Sustainable Finance Disclosure Regulation was introduced in 2021; this is a "European regulation introduced to improve transparency in the market for sustainable investment products, to prevent greenwashing and to increase transparency around sustainability claims made by financial market participants" [42]. We therefore now turn to outlining two impact frameworks that are often used by investors and other (e.g., public policy) actors: the SDGs and Theory of Change.

The SDGs framework was developed by the United Nations [7] to transform our world and improve people's lives and prosperity on a healthy planet. The 17 SDGs, which were adopted by all United Nations (UN) member states in 2015, also serve as guidance for companies seeking to increase their positive impact and decrease their negative impact on society and the environment [43]. Accordingly, the SDGs and especially the more detailed sub-objectives underlying each SDG can help ventures and investors align on what aspects a venture wants to focus on. Therefore, the vast majority of (deep-tech) investors today want early-stage deep-tech ventures to use the SDGs to communicate with them [44].

Another tool that can be used by impact investors is the Theory of Change [26,27]. This tool helps turn the desired impact into concrete actions, by focusing on the mental representations and theoretical assumptions that explain how and why an initiative (e.g., new venture) generates particular changes [26,45]. The Theory of Change (ToC) was initially designed for and used by social programs to evaluate their impact [46] and is rarely used in other settings [47]. While there are several methods for developing a ToC, these methods share the following main building blocks: impact, outcome, enablers, output, activities, and input [48]. In developing a (venture-)specific ToC, the evidence required and assumptions made must be written down: first, the desired impact, or end goal, is formulated; and subsequently, one moves backward to define the required conditions to achieve this end goal; finally, moving further backward results in the activities and input to be delivered to achieve the desired impact [48]. Moreover, deep-tech investors are likely to require ventures to present very detailed impact Key Performance Indicators (KPIs) that allow both the venture team and the investor to monitor the progress toward the desired impact [2].

To conclude, when a deep-tech venture communicates its value proposition to investors, it should not only focus on the customer but also include the impact it has on other societal and environmental stakeholders. This helps to better articulate a convincing narrative, one that deep-tech ventures often lack. Visual tools appear to be highly useful in developing and communicating the value proposition. However, attracting investors is especially difficult for early-stage deep-tech ventures due to the large information asymmetry. Signal theory can be utilized to decrease this information asymmetry. Moreover,

deep-tech investors increasingly focus on societal impact and impact investments are thus rapidly growing. In this respect, two relevant frameworks are the SDGs and the Theory of Change. Finally, deep-tech investors require ventures to develop impact KPIs. However, no integrated tool is available which systematically connects the SDGs and Theory of Change to the value proposition. We therefore design such a tool in the remainder of this article.

3. Methodology

3.1. Research Approach

The aim of this study is to develop a tool that provides guidance on how to effectively communicate the value proposition of a deep-tech venture to investors. We adopt a design science approach to accomplish this. Design Science (DS) approaches have been recommended as a means to bridge the gap between theory and practice in addressing rather complex challenges [49–52]. In this respect, DS serves to create artifacts, as solutions that accomplish specific ends [10,49].

In the study reported in this paper, we first review the literature to identify the various methods available for communicating a value proposition as well as what are key practices and insights in the area of investor communication. Based on this literature review, various functional requirements of an integrated tool for communicating the value proposition of a deep-tech venture to investors are formulated. Subsequently, we describe the design of the initial tool and how this tool is iteratively tested and improved. The testing of the tool was undertaken by means of document study (i.e., retrospectively applying the tool to investment decisions already taken) and interviews and participant observation (i.e., applying the tool in real time to deep-tech investment cases).

Notably, the data collected and analyzed in this paper are qualitative in nature, which is quite common in explorative studies [53] that seek to design and test a new tool, because the number of cases on which such a tool can be tried out is typically not large enough to allow for statistical (significance) tests [51].

3.2. Research Setting

This study was performed at HighTechXL, a deep-tech venture builder located in the Netherlands, which aims to build deep-tech ventures that address grand societal challenges. HighTechXL sources novel deep-tech technologies from leading research institutes such as CERN, European Space Agency, TNO, and Waterloo Institute for Nanotechnology. Additionally, HighTechXL recruits entrepreneurial talents to form venture teams around these technologies, which then enter its venture-building program. This venture-building program focuses on value proposition development, investor engagement, and various KPIs.

3.3. Data Collection and Analysis

All interviews were recorded and transcribed; and all participant observations were written up in field notes. The transcriptions and field notes were subsequently coded. In total, 12 interviews were conducted with 14 people; two of these interviews involved meetings in which two people joined each interview. These interviews were semi-structured, with the list of questions being determined by the maturity level of the prototype of the tool as well as the type of expertise that the interviewee brought to the table. To alpha-test the tool, we interviewed HighTechXL's program manager (3 times), HighTechXL's sustainability officer (3 times), HighTechXL's venture support manager, HighTechXL's CEO, and the managing partner of a deep-tech investment fund. To beta-test the tool, interviews were conducted with the CEO of an early-stage deep-tech venture, the Chief Product Officer and Chief Sales Officer of another deep-tech venture, and the CFO and Sustainability/Operations manager of a third deep-tech venture. Appendix B provides an overview of all interviews.

4. Results

The first part of this section describes various functional requirements for an integrated tool and then presents the tool as a design solution. The second part of this section presents the main results of alpha- and beta-testing the tool.

4.1. Functional Requirements and Design Solution

Based on the literature review in Section 2, the management team of HighTechXL (at which this study was conducted) together with the researchers formulated various functional requirements for the tool. Although the main interest was in communicating a convincing value proposition to investors, we assumed that the tool also had a key developmental role in helping deep-tech venture teams to formulate such a proposition. We thus defined the following requirements:

(a). The tool helps a deep-tech venture team in developing a value proposition that is based on an in-depth understanding of the (envisioned) customers' pains, gains and jobs.
(b). The tool helps a deep-tech venture team uncover and dissect how the value proposition can be brought to life for the envisioned customers.
(c). The tool enables a deep-tech venture team to connect the value proposition to at least one (micro) SDG.
(d). The tool requires a deep-tech venture team to develop and present very detailed impact KPIs.
(e). The tool allows a deep-tech venture team to send as many signals about the value proposition as it deems relevant, to minimize the (perceived) information asymmetry between the investors and the venture team.
(f). The tool has an attractive, user-friendly visual interface.
(g). Finally, the tool exploits and integrates existing tools that are already widely used (to fulfil any of the functional requirements above).

Given these requirements, we designed a preliminary version of the tool that incorporates the VPC [11] as well as the Theory of Change (ToC) framework [26,48], in view of the requirements a, b and g listed above. The other functional requirements implied we designed new components that were subsequently integrated into a broader tool. One of these new components is the 'societal and environmental profile' (addressing requirement c), which was somewhat inspired by the framework developed by Bocken et al. [22]. The other novel component is 'developing impact KPIs' to fulfil requirement d. In view of requirement f, regarding the visual interface, we designed an easy-to-use interface (implemented in a PowerPoint slide set) that guides the user through various stages of developing the value proposition. Finally, the plurality of questions and challenges to be addressed in this integrated tool enables the venture team to create a rich list of 'signals' around its value proposition (see requirement e).

The final solution is the integrated tool outlined in Figure 1. In the remainder of this section, we will describe each stage of the tool in more detail. Given the confidential nature of the (value propositions of the) deep-tech ventures in HighTechXL's portfolio, we will use Tesla as an example in the remainder of this subsection.

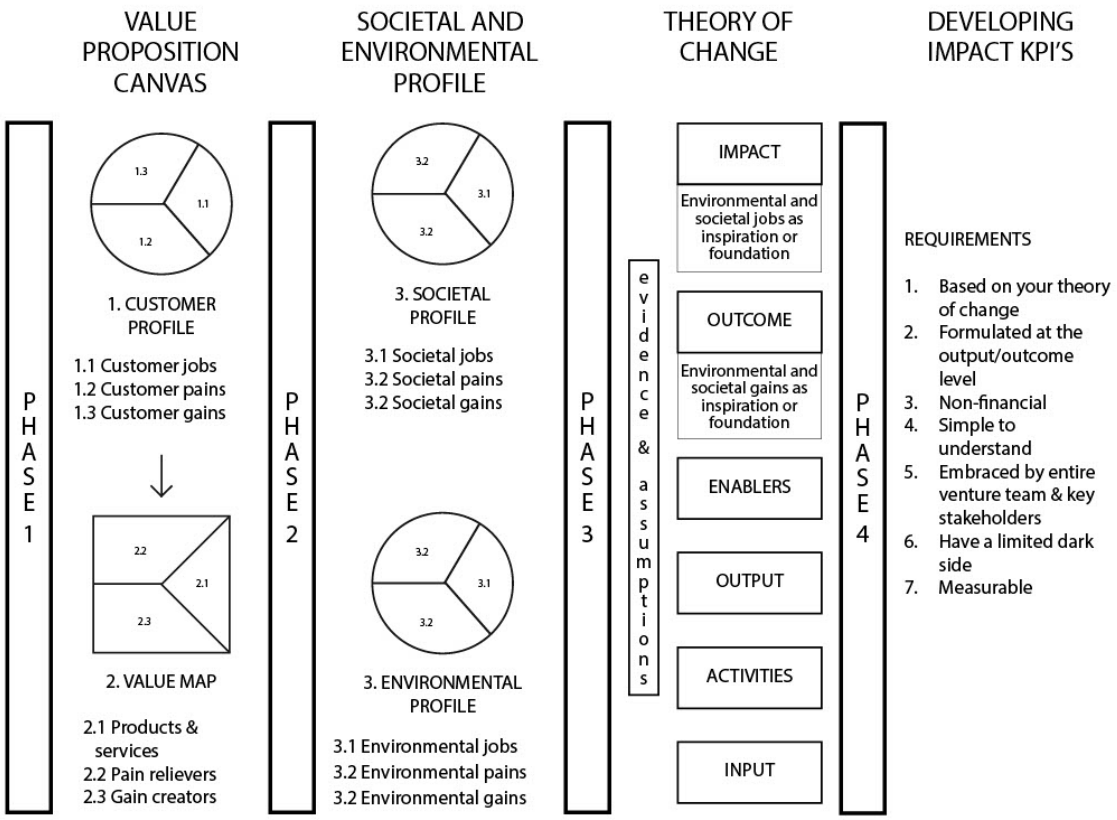

Figure 1. Overview of four phases of the tool.

4.1.1. Phase 1: Value Proposition Canvas

The first phase involves filling out the VPC developed by Osterwalder et al. [11]. This phase focuses on the value proposition for the intended customers of the deep-tech venture. In this respect, it is essential to develop a proper fit between the target customer profile and the value map as described below. Given that the VPC is an existing framework, we only briefly explain this phase here.

The first step is to create a customer profile by gaining a deep understanding of the intended customers. This is carried out by determining the customer jobs, that is, the things a customer wants to get done: these jobs can be functional, social, and/or personal/emotional in nature, but in the context of deep-tech ventures these are very likely (mainly) functional jobs. Subsequently, the customer pains have to be defined, which are major problems that annoy customers before, while, or after performing the respective job or are a potential risk for them [11]. There are three types of pains: undesired outcomes, problems and characteristics, obstacles, and risks. Finally, the customer gains have to be listed. These are benefits and outcomes the customer tries to achieve by performing its job. Four types of gains can be distinguished: required gains, expected gains, desired gains, and unexpected gains [11].

The second step is filling out the value map. Here, the venture team starts by listing all the products and services arising from the venture's value proposition, which are the things that help the customers perform their jobs [11]. There are four types of products and services: physical/tangible, intangible, digital, and financial. Then, the venture team assesses the so-called pain relievers, which describe how their venture aims to decrease the pains experienced by customers [11]. Finally, the so-called gain creators describe how the products and services listed earlier help create value for these customers [11].

The third step after describing the customer profile and the value map is to explore whether there is a fit. This is performed by comparing the customer jobs with the products and services, the customer pains with the pain relievers, and the customer gains with gain creators. In addition, the importance rankings in the customer profile and the value map are also compared. If any of these comparisons implies the fit is not good enough, the venture teams return to the first and/or the second step, and iterates as many times as needed to attain a proper fit. The VPC phase must result in a clear overview of the value proposition for a specific customer (segment), with a focus on the customer-firm relationship.

4.1.2. Phase 2: Societal and Environmental Profile

Phase 2 of the tool starts after completing Phase 1. This phase serves to formulate the impact of the value proposition on other stakeholders then the customers, such as the environment and society. As such, two different profiles need to be developed: the environmental and societal profile. Both of these profiles have a similar structure as the customer profile and consist of societal/environmental jobs, societal/environmental pains, and societal/environmental gains. Figure 2 provides an overview.

The environmental and societal jobs are the things that must be done to make the natural environment or society a better place. We adopted the SDGs as the framework for determining these environmental and societal jobs. When venture teams select environmental jobs, they should consider both positive and negative impacts. For the expected positive impact, one needs to select at least one and up to three SDGs that are relevant to the value proposition (formulated in phase 1). For the negative impact, the venture has to pick at least one SDG relevant to their value proposition, in the area in which this proposition has the most significant negative impact.

After choosing the initial SDGs, the venture team goes deeper within these SDGs to select specific target and/or indicators to be addressed. For example, a deep-tech venture seeking to put autonomous cars on the market not only selects "SDG 3—Ensure healthy lives and promote well-being for all at all ages" [7], but also decides on a micro-target within this SDG. For example, it can target SDG 3, target 6, indicator 1 (or SDG 3.6.1): "by 2030, halve the number of global deaths and injuries from road traffic accidents measured by the death rate due to road traffic injuries" [7]. The venture team then needs to specify how its value proposition will contribute to this SDG 3.6.1 objective. Notably, selecting and completing the 'societal jobs' segment has the same logic as the environmental jobs segment.

After picking one to three SDGs to which the value proposition positively contributes and at least one SDG to which it negatively contributes, the remainder of phase 2 entails filling in the societal/environmental pains and gains (see Figure 2). We focus here again completing the environmental profile; the same logic applies to completing the societal profile. The venture's value map (in phase 1) provides key input here. There is no specific order in which the 'gains' and 'pains' are addressed; this can be done in any order or even simultaneously.

The environmental gains depict how a venture wants to contribute to the environmental jobs defined. There are two types of environmental jobs: required gains and additional gains. Required gains are essential for fulfilling the deep-tech venture's value proposition. If these gains are absent, the value proposition cannot be delivered. For example, the required gain of a venture producing full-electric cars is the increased air quality (due to reduced carbon dioxide emissions), compared to internal combustion-driven cars. If this increase in air quality is not observed, the value proposition cannot be delivered because investors and public policy makers would stop supporting full-electric vehicles.

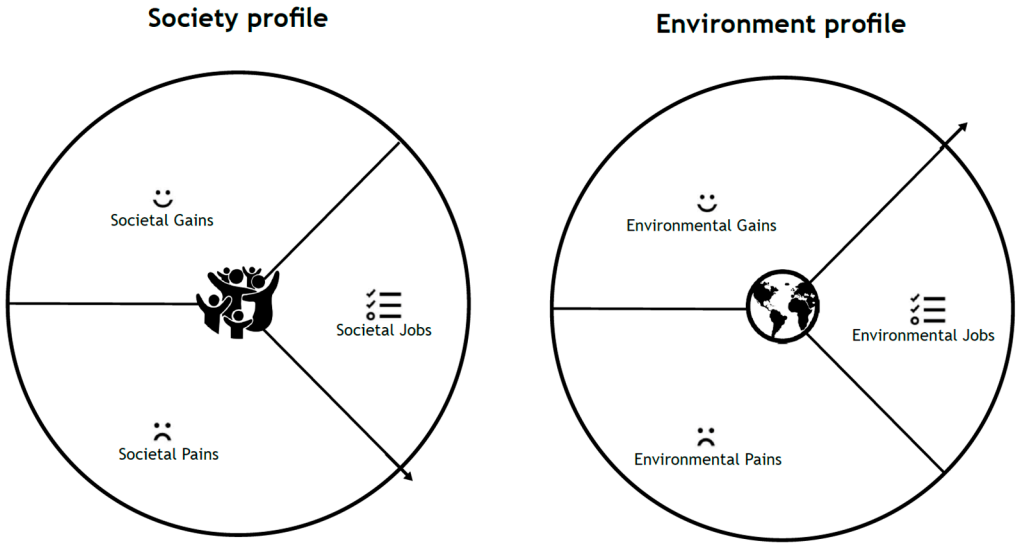

Figure 2. Overview of societal and environmental profile.

Additional environmental gains are extra benefits that less inherently link to delivering the value proposition. For example, full-electric cars could use locally recycled plastics for their interior, instead of less environmentally friendly materials sourced from other parts of the world. However, if such an additional gain is not accomplished, full-electric cars can still be produced and sold. In any case, the venture team should aim to list as many relevant environmental (required and additional) gains as they can think of.

There are also two types of environmental pains: unavoidable and additional pains. Unavoidable pains are outcomes, problems or side effects that are inherently linked to the value proposition. That is, the value proposition cannot be delivered without these negative effects. For example, companies producing full-electric cars would, until recently, use high volumes of cobalt in the batteries used. The mining process of cobalt is known to pollute water, air, and soil by the waste generated, which results in contaminated food and water and reduced crop yields [54]. Without cobalt, however, electric car manufacturers cannot deliver on the promised range of their cars, which is essential to their value proposition. By becoming aware of these negative effects, the venture team can aim to address them. This was also the case for Tesla: half of its newly produced cars no longer contain any cobalt [55].

Additional pains are risks and other negative outcomes that are less inherently linked to the value proposition. For example, in the case of full-electric vehicles, an overheated battery can cause a chain reaction of all battery cells catching fire and/or exploding; high levels of toxic constituents are then released into the environment. The likelihood of such an event is very small and is thus not inherently linked to the venture's value proposition. In any case, by explicitly formulating this type of risk, it can be addressed for instance by means of extra quality checks or adaptations in the product architecture. The additional pains may also help the venture team in defining potential dark sides of the venture's impact KPIs (as addressed later in phase 4). Again, one should aim to list as many relevant pains as possible. Once phases 1 and 2 are completed, an extended version of the Value Proposition Canvas is available. Figure 3 provides an example of such a canvas.

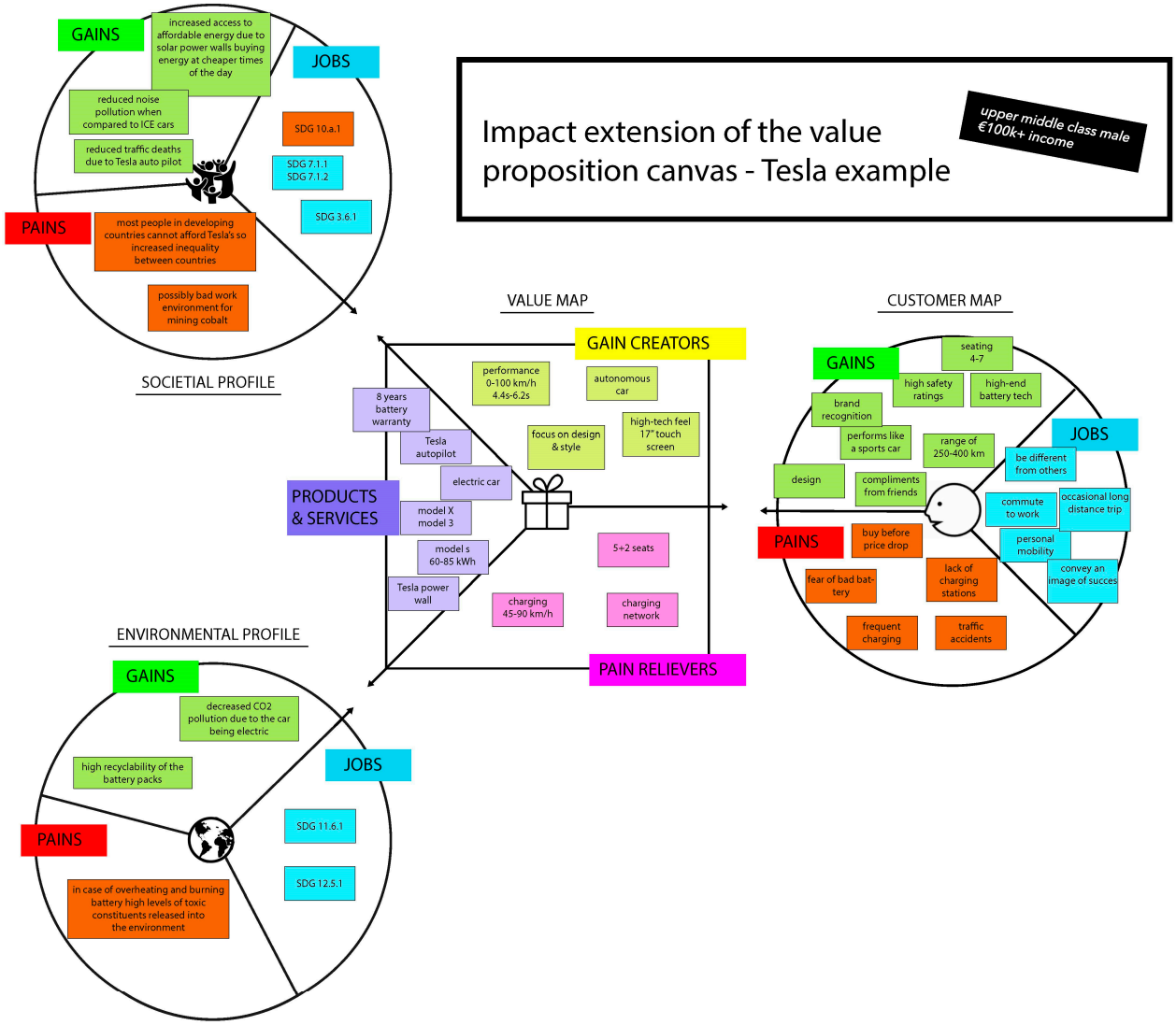

Figure 3. Example of societal and environmental profiles (as extension of VPC).

Notably, this example also demonstrates that the SDGs in the societal and environmental profile typically have to be specified at the micro-indicator SDG level connected to one of the targets formulated for each SDG. For example, in the societal jobs and environmental jobs in Figure 3, we refer to six of these indicators (linked to five targets embedded in SDGs 10, 7, and 3 respectively SDGs 11 and 12). The targets and indicators formulated in the societal jobs are:

- Target 10.a: Implement the principle of special and differential treatment for developing countries, in particular least developed countries, in accordance with World Trade Organization agreements—with indicator 10.a.1: proportion of tariff lines applied to imports from least developed countries and developing countries with zero-tariff.
- Target 7.1: By 2030, ensure universal access to affordable, reliable and modern energy services, measured in terms of (indicator 7.1.1) the proportion of the population with access to electricity and (indicator 7.1.2) the proportion of the population with primary reliance on clean fuels and technology).
- Target 3.5: Strengthen the prevention and treatment of substance abuse, including narcotic drug abuse and harmful use of alcohol—indicator 3.5.1: coverage of

treatment interventions (pharmacological, psychosocial and rehabilitation and aftercare services) for substance use disorders.

- The targets and indicators in the environmental jobs are:
- Target 11.6: By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management—indicator 11.6.1: proportion of municipal solid waste collected and managed in controlled facilities out of total municipal waste generated by cities.
- Target 12.5: By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse—indicator 12.5.1: national recycling rate, tons of material recycled.

4.1.3. Phase 3: Theory of Change

The third phase of the tool targets at developing a specific Theory of Change (ToC). The ToC phase serves to uncover and define what intermediate outcomes have to be achieved and what activities have to be performed to achieve those outcomes, also because the ambitions and objectives formulated in the previous phase are often not specific enough for (impact-oriented) investors. Moreover, a detailed ToC roadmap serves to send an extra signal to the investor (see Section 2.2) regarding the carefulness and foresight demonstrated by the venture team.

We draw here on the ToC guidelines developed by Harries, Hodgson and Noble [48]. The building blocks of a ToC are: final impact, intermediate outcomes, outputs, activities, inputs, enablers, internal enablers, external enablers, evidence, and assumptions (see Appendix A for detailed definitions). The first step in developing a ToC is defining the final impact a venture wants to make. The final impact should be long-term, realistic and beneficial to a specific (environmental or societal) stakeholder. The societal and environmental jobs defined in phase 2 should be used as the foundation here.

The second step is to work backwards from the final impact and define the intermediate outcomes necessary for achieving this impact. Harries et al. [48] describe these intermediate outcomes as potentially the most critical step in developing a ToC. The intermediate outcomes should be relatively short-term, feasible, and (indirectly) influenceable by the venture team. The societal and environmental gains defined in Phase 2 can serve as a starting point because these describe the intermediate steps of the venture toward its social and environmental jobs.

The next steps are to define the outputs delivered by the venture team to achieve the intermediate outcomes and the activities and inputs required to generate these outputs. The outputs are often quantifiable, for example, the number of people saved, metric tons of carbon footprint reduced, the number of products sold per week, and so forth. The output can help quantify certain parts of the ToC and provide guidance on what evidence to collect for monitoring its effectiveness. If some of the activities and inputs defined appear to be not (yet) available, the venture team can shift its attention to acquiring these inputs and prioritizing these activities. For example, new specialized staff members are hired, additional office space is rented, or extra cleanroom capacity is rented.

Subsequently, the enablers are uncovered and defined: these are the conditions required for the impact to materialize. There are two types of enablers: internal enablers and external enablers. The venture team can directly influence the internal enablers, but not the external enablers.

Finally, throughout the process of developing the ToC, one should consider what evidence already is available to support this ToC and what evidence still has to be collected. If the ToC lacks a lot of evidence, the venture team needs to identify and list the assumptions made in the various steps of its ToC. F. Figure 4 provides an example of a ToC.

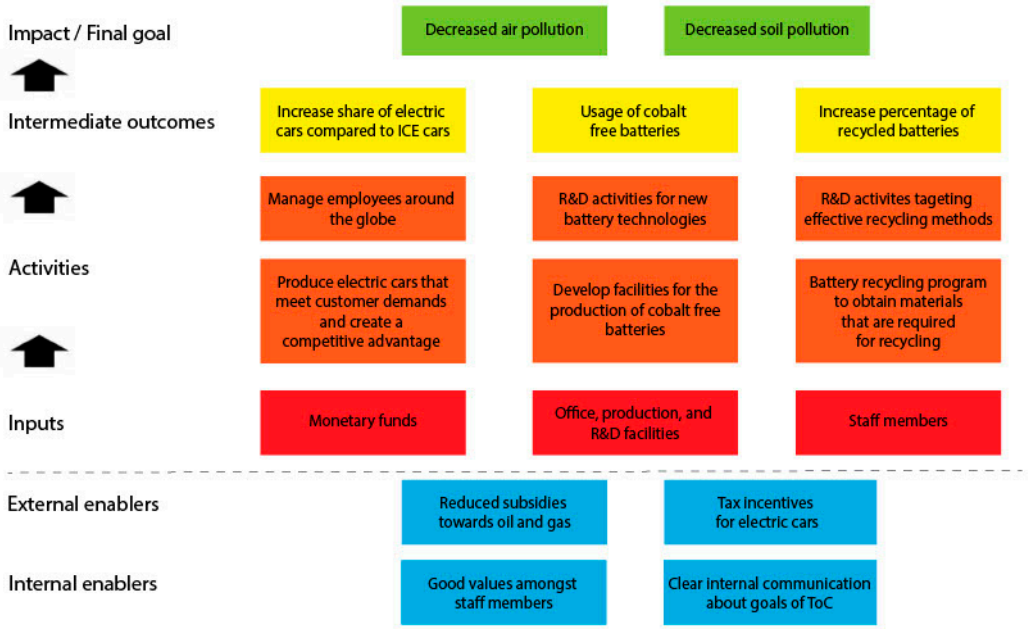

Figure 4. Example of Theory of Change (ToC).

4.1.4. Phase 4: Impact KPIs

The final phase of the tool involves the development of impact Key Performance Indicators (KPIs), which allow deep-tech ventures and their investors to monitor the progress toward achieving the final impact formulated in the ToC phase. This fourth phase is critical because KPIs focus on the aspects of a venture's performance that are the most critical for its current and future success [56]. While different types of impact KPIs exist, the focus in this study is on venture-specific impact KPIs, as these should be based on the ToC developed in phase 3. As the Theory of Change is different for each venture, their respective impact KPIs also differ, hence the term venture-specific impact KPIs.

Furthermore, seven requirements of KPIs appear to be critical. The first two KPIs defined below arose from the alpha testing of a preliminary version of the tool (see Section 4.2). The other five are based on Parmenter's work [56] and were also validated in the various tests described later. Accordingly, venture-specific impact KPIs must be:

(1) Based on the ToC developed in phase 3—The KPIs describe how a venture intends to measure its impact. The ToC serves to deliver this impact. By linking the venture-specific impact KPIs to the ToC, one ensures that the activities performed contribute to these KPIs and the latter contribute to the final impact.
(2) Formulated at the output/outcome level of the ToC—The output/outcome levels are the last levels that the venture team can directly influence.
(3) Non-financial—The KPIs should be non-financial but nonetheless formulated in volumes or percentages. That is, the KPIs should not be about, for example, return on investment or net profits, but address the (monetary) value of, for instance, reduced carbon dioxide volumes, absence of toxic output in the air, or decreasing numbers of car accidents.
(4) Simple to understand—All relevant stakeholders should immediately understand what is meant by the KPI.
(5) Embraced by the entire venture team and key stakeholders—This broad support ensures all participants (including investors) perform their activities with the same targets in mind.

(6) Have a limited dark side—This targets the potential negative influence measuring one aspect can have on other aspects of the business. The environmental and societal pains formulated in phase 2 of the design solution can serve as inspiration for the dark side of your impact KPI. An example is a venture that seeks to develop an app that provides travelers with historical as well as actual (real-time) information on the on-time arrival of buses, trains and other forms of public transport; this type of app may motivate managers of public transport companies to create incentives and sanctions for (e.g., train) drivers' performance; the shadow side of the on-arrival KPI is that drivers may reduce the times that doors open at a (couple of) station(s) to ensure on-time arrival at the next station, which in turn may decrease the level of service and customer satisfaction [56].
(7) Measurable—The KPIs should be easy to measure.
(8) In the Tesla case, the KPIs for its first electric vehicle offered at the time could have been, for example:
    - in the next five years, we want to sell 3 million Tesla Model S cars;
    - we aim to increase the number of batteries without cobalt installed in these cars to 80% in the second year and 95% in the third year;
    - in the next eight years, we will increase the percentage of batteries that are fully recycled from (currently) 30% to 90%.

4.2. Alpha and Beta Tests of the Tool

We sought to test and validate the (various versions of the) tool by means of a highly iterative process. The early prototypes of the tool were reviewed by experts within HighTechXL (all with extensive experience in supporting and guiding deep-tech ventures). We conducted these alpha-tests of the tool and improved it accordingly until any significant issues were no longer raised in these tests. Appendix B provides an overview of these alpha-tests. For the beta-testing phase, we invited several deep-tech venture teams (enrolled in HighTechXL's venture building program) to apply the tool. An overview of the beta-tests is also provided in Appendix B. The data regarding these ventures are anonymized, for reasons of confidentiality.

The alpha-tests served to iteratively design and prototype the tool, with feedback from various internal experts in HighTechXL as well as an experienced deep-tech investor (see Appendix B for more detailed info). A key insight arising from various alpha-tests was the need to keep the VPC as a separate phase in the tool, rather than trying to build an (SDG-related) extension directly on the VPC platform. The alpha-testing phase also provided the opportunity to review three Final Investment Recommendation (FIR) documents in-depth, which served to apply the tool retrospectively on investment decisions recently taken by a deep-tech investment fund. These FIRs outline all aspects of the venture that the investors perceive to be critical. We used these FIR documents to check whether the signals incorporated in the tool align well with the sustainability aspects listed in these documents and adapted the tool accordingly. HighTechXL's CEO made the final decision that the fifth prototype of the tool was deemed to be ready for beta-testing.

The beta-tests were conducted by three early-stage deep-tech venture teams. The first test was performed by the CEO of a deep-tech venture, the second test by the Chief Product Officer and Chief Sales Officer of another deep-tech venture, and the third test involved the Chief Financial Officer and the Chief Operations Officer (also responsible for sustainability impact) of a third deep-tech venture. Various details of these tests were anonymized and deleted from Appendix B, for reasons of confidentiality.

Overall, these beta-tests demonstrated that the tool is complete and very useful for fleshing out the societal and environmental impact of a deep-tech venture's value proposition and operationalizing this impact in specific KPIs. Moreover, the tool appears to support deep-tech ventures in developing not only a well-formulated sustainability dimension of their value propositions, but also dissects these propositions into outputs,

activities, milestones, enablers, and so forth—which increases the number of explicit signals about the value proposition to potential investors. In terms of the functional requirements defined in Section 4.1, we can thus conclude that the tool fulfills all requirements formulated.

5. Discussion

This study served to design and test a tool that supports deep-tech ventures in effectively communicating (the sustainability aspects of) their value proposition to investors, long before the market validation can take place via the first customers being served. Drawing on a design science approach, we reviewed the literature, developed a set of functional requirements, and subsequently designed, prototyped and tested the tool. The final version of the four-phased tool draws on and extends existing tools such as the VPC and ToC. The sustainability impact of a venture's value proposition was incorporated in the tool by means of the SDGs framework.

The main contribution of this study is the development of a tool that connects and integrates extant tools such as VPC [11] and ToC [26,27] in a systematic approach that also incorporates the SDGs and results in specific KPIs that help investors monitor the progress a venture makes regarding its value proposition. The tool also draws on signaling theory [31], in the sense that it provides a platform to increase the number and mutual consistency of signals about the value proposition to investors [35], which increases the likelihood that the latter will trust the overall message of the venture team. As such, our study provides a novel tool for developing deep-tech value propositions, which combines various existing tools as well as incorporates a strong sustainability dimension.

More specifically, the tool designed and tested in this study will enable deep-tech entrepreneurs to better articulate their 'impact' narrative and thereby effectively tap into the large pool of capital available for SDG impact investments—estimated to be 39 billion euros [8] worldwide. In turn, increased investment volumes will help these entrepreneurs to develop and distribute deep-tech solutions for SDGs such as clean water and sanitation, sustainable cities and communities, climate change, and affordable and clean energy.

The main limitation of our study arises from the fact that the tool was tested in a Dutch venture builder that focuses on early-stage deep-tech startups. Accordingly, the tool was not fully tested in ventures that successfully acquired both Series A and Series B investments. Future research will therefore have to establish whether the tool truly supports deep-tech ventures in the entire journey from early-stage startup to large scaled-up companies. In the deep-tech area, this journey may take up to 15 years [3] which implies future work needs to adopt longitudinal research designs to establish the long-term effects of the tool presented in this article. If the number of cases analyzed in such longitudinal studies is sufficiently large, one can also adopt quantitative metrics and statistical analysis to determine the effects of this tool.

With regard to the tool itself, future research can explore whether the positive and negative contributions to the SDGs can be quantitively weighed (see alpha test eight in Appendix B). By even more explicitly including the negative impact of any deep-tech value proposition, the tool also becomes less likely to be used for greenwashing purposes [57].

Another point of improvement to be addressed in future work is the practical delivery mode of the tool. The current tool involves a set of PowerPoint slides [58]. Future work may serve to develop a website that provides an online version of the tool as well as access to examples and other resources, possibly as part of a broader set of tools for (deep-tech) entrepreneurs and their investors. Such an online mode also provides ample opportunities for scholars as well as entrepreneurs and investors to develop a repository of cases on which the tool was applied and thereby grow a cumulative body of knowledge in this area.

Another point of attention for future work is that the SDGs incorporated in the tool were signed by all UN member states in 2015, with the overall objective of accomplishing

these SDGs by 2030. Consequently, the SDGs framework will very likely be reformulated and extended around 2030. In case of major changes in this framework, the tool developed in this paper will also have to be adapted.

6. Conclusions

Deep-tech startups have enormous potential to solve major societal challenges, but they have extremely long development times and thus require substantial amounts of investment capital long before the first customer can be served. Moreover, potential investors increasingly expect that the value proposition of a deep-tech venture has a clear sustainability dimension. We therefore designed a tool that serves to develop a value proposition that can effectively convince investors, one that is explicitly connected to the SDGs. This tool can help deep-tech entrepreneurs to develop a value proposition that is more likely to attract early-stage investors.

Supplementary Materials: This article is based on the MSc graduation project of Joppe Schutselaars at Eindhoven University of Technology. More details on the design and testing of the tool described in this article are available in Schutselaars [58]. The complete tool is available as a slide set from: https://doi.org/10.13140/RG.2.2.24144.99841/1 (accessed on 5 March 2023).

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Abbreviations

CEO	Chief Executive Officer
CFO	Chief Financial Officer
DS	Design Science
FIR	Final Investment Recommendation
KPI	Key Performance Indicator
SaaS	Software as a Service
SDG	Sustainable Development Goal
ToC	Theory of Change
UN	United Nations
VPC	Value Proposition Canvas

Appendix A

Table A1 below provides an overview of the main building blocks of the ToC (used in phase 3 of the tool).

Table A1. Overview of Theory of Change (adapted from [56]).

Final Impact	The Broader Social Change that Your Venture is Trying to Achieve.
Intermediate outcomes	The short-term changes, benefits, learning or other effects that result from the venture's value proposition. These short-term steps will contribute to a final impact and may include changes in users' knowledge, skills, attitudes, and behavior.

Outputs	Products, services, or facilities that result from your venture's activities. These are often expressed quantitatively (e.g., carbon dioxide concentration, kilowatt hours, number of users).
Activities	The things that the venture needs to do. Activities remain within the venture team's control.
Inputs	The resources that go into the venture to be able to carry out its activities.
Enablers	Conditions that need to be present or absent to allow the venture to succeed. The presence or absence of enablers can help or hinder the venture. There are two kinds of enablers:
Internal enablers	internal enablers need to exist inside the venture for a ToC to work, and are mostly within the venture team's control. These are the mechanisms (e.g., quality management of its production process) by which the venture delivers its outputs.
External enablers	External enablers need to exist in the external environment for the ToC to work; they are often beyond the venture team's immediate control. External enablers often involve sociocultural, economic and/or political conditions, including prevailing laws, regulations, and (opportunities to develop) close collaborative ties with other companies.
Evidence	Information you already have or plan to collect that is relevant to supporting or testing the ToC.
Assumptions	The underlying beliefs about how the venture's value proposition will evolve, the business partners involved, and the broader context. These assumptions are often (initially) implicit in your ToC; by uncovering and explicitly stating them, you become alert and responsive to major external changes that affect the progress and success of your venture.

Appendix B

The two tables below provide an overview of the alpha- and beta-tests conducted.

Table A2. Overview of alpha-tests (conducted from May to November 2022).

Test	*Version*	*Goal*	*Outcome*	*Decision*
α 1	Initial solution design	Concept testing with the program manager, to decide whether to extend the VPC by incorporating environmental and societal impact.	This initial solution is in the right direction and has potential, but needs to be further elaborated upon.	The initial idea for the solution will be further refined in the same direction. The SDGs will be included.
α 2	First prototype	Validate the added value of the prototype with the Sustainability Officer.	It could definitely be of added value. Good integration of SDGs. To provide applicability to investors it should be combined with a Theory of Change (ToC).	Think about a way to incorporate the ToC in the tool.
α 3	First prototype	Get a better perspective on what is important for an investor in a meeting with the managing partner of a deep-tech investment fund.	The tool should be able to develop venture-specific impact KPIs. In beta tests, later-stage startups should also be incorporated as they have a more tangible focus on sustainability.	Tool is very useful. The interviewee also provided access to three Final Investment Recommendation (FIR) documents, to obtain an in-depth insight in the sustainability aspects that investors focus on.
α 4	Second prototype	Review the improved extension (i.e., V-model) of the VPC and discuss the potential of	The V-model has potential. The extension of the VPC is getting shape with the current listing of pains, gains, and jobs. Think about developing a standard profile for each SDG.	Further elaborate upon the V-model. Develop standard profiles for each SDG, where the job will be the generic SDG and its targets and indicators

		using ToC with the program manager.		will become the pains and gains.
α 5	Third prototype	Gain insight into how impact KPIs are developed and can be linked to ToC with the Sustainability Officer.	The impact KPIs are based on the ToC and should be developed at the output/outcome level.	Integrate the findings with regard to KPIs into the tool.
α 6	Fourth prototype	Discuss the new method of integrating the ToC into the tool and possible integration of the tool with the VPC with the program manager.	Tool is shaping up really well; curious about what the final result will be. Keep the tool simple: do not integrate it with the VPC.	Do not try to integrate the other phases of the tool into the VPC; keep the latter as a separate first phase.
α 7	Fourth prototype	Validate the readiness for beta-testing with the Sustainability Officer, with a focus on the SDG phase.	Good that the tool highlights both positive and negative environmental and societal impacts: it is important not to motivate the user to only spell out positive influences, when these are hard to find. The tool can also be used as part of a CRM system. There could be different types of impact KPIs: venture-specific ones and generic KPIs for all ventures.	No further changes need to be made to the tool.
α 8	Fourth prototype	Validate the current prototype with a venture support manager.	The foundation of the tool is good. Currently the slides still need a bit of explanation to fill out the tool. The dark side in the impact KPIs can be linked to environmental and societal pains. Future work should explore whether the negative/positive SDGs impacts can be effectively weighed against each other.	More elaborately explain the tool and its usage in various slides. In addition, develop new slides to show a completed example (using public data on Tesla). No other changes needed.
α 9	Fifth prototype	Decide with the CEO whether the tool is ready to start beta testing with ventures.	Tool is ready for beta testing.	Start with the beta-tests.

Table A3. Overview of beta-tests (conducted in November-December 2022).

Test	*Version*	*Goal*	*Outcome*	*Decision*
β 1	Fifth prototype	CEO of an early-stage deep-tech venture uses the tool.	The extension of the VPC is strong. The framework leads to new insights, especially on the pains side. Requirements for impact KPIs were clear.	No further changes needed based on this test.
β 2	Fifth prototype	Chief Product Officer and Chief Sales Officer of an early-stage venture together apply the tool.	This is a very useful tool. Better than the widely used VPC, which provides limited opportunities to look at negative aspects; risk analysis does exist in VPC, but focuses solely on system itself. This tool includes external stakeholders and has strong linkage with the SDGs. The tool could also be used for quick analysis of the effects of different supply chain choices. Can be	Change order of the slides to match the template. Reconsider the necessity of making (all) impact KPIs non-financial.

			difficult to make all KPIs non-financial. When selecting SDGs, try to go to the level of micro-targets and/or indicators.	
β 3	Sixth prototype	The CFO and Sustainability/Operations manager of an early-stage deep-tech venture apply the tool.	Tool is very easy to use; proper results can be achieved within an hour. Good that the tool also focuses on the negative impact; many ventures do not take that into consideration, which implies only the good parts are highlighted to potential investors. This test also provided new insights for this specific venture team.	The tool does not need any further changes. A few spelling errors in the slides have to be adjusted.

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