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Sustainable Entrepreneurial Process in the Deep-Tech Industry

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Abstract: To date, deep-tech entrepreneurship and sustainable entrepreneurship are both attracting the interest of researchers. Indeed, deep-tech is being employed to address future sustainable challenges in the present. Nevertheless, the process of deep-tech startups is filled with distinct obstacles. These types of startups may necessitate more targeted sustainable entrepreneurial process and specialised knowledge compared to conventional technological startups or general sustainable entrepreneurial process. Currently, there are only publications discussing either a sustainable entrepreneurial process or conventional technical startups. Therefore, the aim of this article is to investigate the process of sustainable entrepreneurs as they transition from startup ventures to scaleup enterprises within the context of deep-tech industry. Based on previous sustainable entrepreneurial processes, a multiple case study was conducted within six deep-tech startups in order to find out the sustainable process pattern. A conceptual model of sustainable entrepreneurial process in deep-tech industry is established including five phases with six activities: (i) Sustainable idea definition; (ii) Sustainable opportunity recognition and evaluation; (iii) Venture launch; (iv.i) Sustainable products/ services development; (iv.ii) New sustainable enterprise financing; and (v) Sustainable enterprise scaleup. This process enables sustainable deep-tech entrepreneurs to necessarily have an overview of key entrepreneurial stages to navigate from the startup to scaleup process.

Keywords: sustainable entrepreneurship; deep-tech; entrepreneurial process; deep-tech entrepreneurship

1. Introduction

International competitive advantages are no longer primarily assessed by comparing countries' revenues. Sustainability, technology, and digital competitiveness also impact it [1]. The transition to the digital economy has resulted in the emergence of a new type of entrepreneur with distinct characteristics. Sustainable entrepreneurship offers innovative solutions that adhere to triple bottom line values, tackle traditional societal and environmental challenges [2,3] and reach sustainability [4].

Notwithstanding the increased focus of scholars, policymakers, practitioners, and the media on sustainable entrepreneurship, the empirical construct remains nascent. Sustainable entrepreneurial processes (SEPs) are crucial for practical applications in understanding sustainable entrepreneurship beyond academic research [5]. Shepherd and Patzelt [6] propose investigating sustainable entrepreneurship as a novel research subject and empirical phenomenon. There is limited scholarly study on the sustainable entrepreneurship process [7] due to the fact that process research necessitates a meticulous examination of complexity within a long-term context [5,8,9]. There is also a lack of a customized and sustainable entrepreneurial process designed particularly for a certain industry [9], specifically the technological industry.

A deep-tech enterprise often integrates several technological innovations into a disruptive solution within domains such as healthcare, sophisticated robotics, clean-tech, or energy storage [10]. Regardless of the sectors they operate in, deep-tech companies develop products that address critical

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issues confronting humanity and the earth, such as climate change, disease, and food scarcity [11], hence contributing to the Sustainable Development Goals [12,13]. Deep-tech innovations involve a combination of highly intricate software and novel forms of complex hardware, making them more complex than their software-driven counterparts [14,15]. Deep-tech is primarily based on scientific discoveries or technical breakthroughs, which include transforming theoretical possibilities into practical implementations. Deep-tech, unlike conventional tech, prioritises the redefinition of limits and reshaping of established paradigms, rather than refining existing technologies and making incremental improvements [13].

Comparing to a purely technological startup, a deep-tech venture has a high barrier to entry [10], as it has a longer research and development process [16], a higher initial investment cost, and fewer successful organizations in this field to be referenced to [10]. They are typically founded by highly skilled entrepreneurs with PhDs or postgraduates [17]. This distinguishes deep-tech startups from traditional technological startups [18]. The failure rate of deep-tech ventures is therefore 90% or higher due to those traits [19,20]. Due to its novelty in the field of entrepreneurship and its connection to developing technologies, there is a limited amount of research available on deep-tech topics, as well as the necessary circumstances to facilitate this activity [17,21].

There is currently no specific entrepreneurial process tailored for deep-tech entrepreneurs that can provide them with a comprehensive understanding and guidance throughout the startup and scaleup journey. Deep-tech is important for not only economic growth but also sustainable development. However, starting a deep-tech business can be challenging [22]. Therefore, the question raised is that how do sustainable entrepreneurs generate ideas, recognize, develop, and exploit opportunities, as well as scale up the business in the context of deep-tech industry? The aim of this article is to investigate the process of sustainable entrepreneurs as they transition from startup ventures to scaleup enterprises within the context of deep-tech industry. This article bridges the gaps between two prominent entrepreneurial topics, sustainable entrepreneurship and deep-tech entrepreneurship. In light of this, it is necessary to examine the startup process for scaling deep-tech successfully so that we may draw similarities and differences between the existing sustainable entrepreneurial process [5,8,9] and that of deep-tech ventures. The process model is expected to contribute to the literature on sustainable entrepreneurship and the deep-tech industry.

The remainder of this paper is organized as follows: literature review, research methodology, findings, discussion, and conclusions.

2. Literature Review

The entrepreneurial process and opportunity identification are interconnected through sustainable entrepreneurship [23].

Choi and Gray [8] examined 21 accomplished sustainable entrepreneurs in the fields of food, fashion, and biotechnology, studying their methods during crucial stages of their businesses. Their study shows that the majority of sustainable entrepreneurs come from unique backgrounds, utilise non-traditional sources of funding, and implement unconventional yet successful human resource management strategies. Sustainable entrepreneurs manage their company differently from its inception to its exit. Entrepreneurship involves five key stages, recognition of an opportunity, assembly of resources, launching the venture, managing the growth, and harvesting the business. However, they analyse established companies such as Migros and Patagonia, focusing on seizing opportunities rather than discovering them. Their primary discovery is that the majority of successful businesses are in the highest market segment. This allows them to transfer the increased expenses of sustainable enterprises to customers and manage economic, social, and environmental considerations.

Belz and Binder [9] recommend that sustainable entrepreneurs initiate a firm gradually in order to optimise the process and preserve resources. Drawing from four case studies, the research presents the six phases of the sustainable entrepreneurial process: recognising a social or environmental opportunity, developing a double line solution, developing a triple bottom line solution, funding and forming a sustainable enterprise, and creating or entering a sustainable market [9]. The study

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discovered that the triple bottom line, which encompasses ecological, social, and economic objectives, is being incorporated gradually. The authors indicated that further research is required to comprehend this phenomenon. Also, the research fails to specify the precise manner in which entrepreneurial activities ultimately facilitate sustainable goals.

Matzembacher et al. [5] conducted a study involving eleven organisations spanning six countries and diverse sectors, including both for-profit and not-for-profit enterprises. The results pertain to a sequence of processes that take place prior to the ideation process, including idea generation, opportunity recognition, opportunity development, venture launch, and positive impact. The sustainable entrepreneurial process ends only when it generates a positive impact. Similar to Belz and Binder [9] process, the integration of sustainability dimensions does not occur simultaneously or prior to venture launch. Therefore, according to the researchers, misclassifications may result from assuming that the process is complete during the venture launch phase.

The Belz and Binder [9] process model and the Matzembacher et al. [5] process model are selected in order to establish appropriate analytic categories for this inquiry. Firstly, both of the process models include for-profit ventures, making it particularly well-suited for deep-tech ventures. Secondly, the model developed by Matzembacher et al. [5] represents the most recent advancements in sustainable entrepreneurial processes. This model addresses the limitations of prior approaches to sustainable entrepreneurial processes. However, the process is lacking in the funding stage, which is vital for a deep-tech venture. Therefore, a combination of both would bring more completion in the deep-tech context.

3. Research Methodology

3.1. Multiple Case Study Design

The study applied the narrative strategy through multiple case studies to examine the fundamental steps of sustainable entrepreneurial processes and the patterns that emerge within the sequence of events. By applying Yin's research strategy framework [24], a sustainable entrepreneurial process is examined over an extended period. The researchers had limited influence over the actual behavioural events documented in the article, such as identifying a sustainable idea, identifying of a sustainable opportunity, evaluating its feasibility, product development, obtaining funding, and creating sustainable value. Furthermore, a significant portion of the events occurred prior to the investigation's start and were associated with current circumstances. Considering Yin's framework, the adoption of the case study technique appears to be the most appropriate approach for developing a sustainable business process.

The selection criteria included enterprises who had introduced at least one product or service to the market, as well as the segment's size and maturity [25]. The most significant factor was the firm's demonstration of social or environmental values that were consistent with the research aims. The crucial benchmark within the market segment was the introduction of new products or services, and was supported by external financing sources [21]. Accordingly, six case studies were selected and marked autonomously as described in Table 1.

Table 1. Description of selected case studies.

Enterprise	Year of established	Fields	Founder	Triple bottom lines value
Enterprise A	2015	Recycling	Dr. A1	Economics Environment Societies
Enterprise B	2017	Heating, ventilation and air conditioning (HVAC)	Founder B1 Founder B2	Economics Environment
Enterprise C	2013	Energy	Founder C1 Founder C2	Economics Environment

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Enterprise D	2016	Automation	Founder D1 Founder D2 Founder D3	Economics Environment Societies
Enterprise E	2015	Automation	Dr. E1	Economics Societies
Enterprise F	2018	Security	Founder F1 Founder F2	Economics Societies

The sustainable deep-tech enterprises served as the basis for analysis. The study's external validity was enhanced by the inclusion of instances from various businesses (recycling, HVAC, energy, automation, and security) and countries (the United States, Canada, and France). A diverse variety of sustainable deep-tech firms provided a stronger foundation for theory [26].

3.2. Process Research Strategy

Langley [7] conducted an extensive examination of seven unique methodologies used in the conceptualization of process data by evaluating generalizability, simplicity, and precision [27,28]. This study collects and analyses data using the narrative strategy. The narrative strategy is frequently viewed as a critical component in the process of making meaning within businesses, and strategic practices naturally include multiple layers and forms of narrative [29]. The use of narrative technique in research is highly accurate, yet it can introduce complexity and reduce generality [7].

3.3. Data Collection

Data were collected using search engines including Google, EMIS (Emerging markets research, data, and news), and the Pitchbook yielded primary sources of information. The search terms utilised encompassed not only the names of the organisations but also those of their founders and co-founders. The secondary data comprised a diverse range of sources that pertained to the sustainable entrepreneurship process, including but not limited to a company's website, blog posts, press releases, videos, founders' speeches, social media platforms, and print media. In order to enhance the external validity of the data, it is vital to ascertain that a minimum of two independent reference sources provide support for each particular occurrence. After being obtained, the recently collected data was subsequently imported into the database and subjected to standardisation in the spreadsheet.

3.4. Data Analysis

A process is a series of events that explains how entities develop throughout time [30]. An event is defined as an uncommon happening that is both shared and public in nature, acting as a symbolic representation of the transition from one system or temporal condition to another [31]. After identifying the events, they are classified according to pre-set attributes to simplify the information [7]. Coding in qualitative research entails the act of dividing data into separate components [32] and then organising them into categories that facilitate comprehension, facilitate comparison, and contribute to the construction of theoretical frameworks [33]. The events were categorised based on the sustainable entrepreneurial process [5,9]. Subsequently, the actions performed by both the entrepreneurs and the events were classified to precisely depict their essential events. The coding accuracy was verified by conducting inter-coder reliability experiments [34,35].

After the codes were determined, the narrative strategy was used to encode the events of each occurrence. Furthermore, cross-case study analysis was conducted, focusing on the sustainable entrepreneurial process [36] to identify repeating patterns, construct conceptual frameworks, and examine similarities and differences within the collected data. Finally, a thorough examination of existing literature was conducted to validate and analyse the sequential order of the process.

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4. Results

The analysis results show that a technological background is crucial for sustainable deep-tech entrepreneurs. The sustainable entrepreneurial process in the context of the deep-tech industry includes five phases with six activities: sustainable idea generation, sustainable opportunity recognition and evaluation, sustainable opportunity exploitation, sustainable deep-tech development, sustainable enterprise financing, and finally scaling up the sustainable enterprise.

4.1. Technological Background

Through the examination of six case studies, it was revealed that all of the founders had technical expertise prior to embarking on their entrepreneurial activities. Dr. A1, a member of the Enterprise A team, holds a degree in Control and Dynamic Systems and possesses extensive expertise in algorithm development and artificial intelligence. Founder B1, the founder of Enterprise B, holds a bachelor's degree in Industrial Engineering and possesses substantial proficiency in technology. Founder B2, Enterprise B's co-founder and partner, has demonstrated adeptness as a leader in several sectors and has significantly contributed to the company's development endeavours. As per the Enterprise C case study, Founder C1 holds a Life Science and Cleantech Engineering degree and has accumulated fourteen years of professional experience as a consultant with a specialisation in cleantech and energy efficiency. Founder C2 brings expertise in the energy service sector to the partnership. As per the Enterprise D case study, the three co-founders possess doctoral degrees in engineering and additional expertise in the technology sector. Without prior technological knowledge, Founder F1 hired Founder F2 as a co-founder of Enterprise F, who possessed a four-year background in artificial intelligence, focusing on AI development and implementation. Dr. E1, the founder of Enterprise E, holds a Doctor of Philosophy degree in Cognitive Science or Artificial Intelligence from Stanford University.

4.2. Sustainable Idea Generation

The majority of the examined case studies revealed that the initial stage of the sustainable entrepreneurship process involves the generation of a sustainable idea. This study analysed six case studies to find three essential components that lead to the definition of a sustainable concept: individual enthusiasm for technology and scientific investigation, professional proficiency, and the recognition of sustainable deficiencies. A sustainable idea is defined by a combination of personal interests in technology and scientific research. The founder of Enterprise A was motivated by technical progress to enhance the efficacy of the waste recycling process. Then, Dr. A1 collaborated with the Closed Loop Fund and the Carton Council to acquire comprehensive insights into the industry. The founders of Enterprise D were interested in the potential of artificial intelligence to make significant contributions to both the economy and society. Following a comprehensive assessment, a resolute decision was reached to invest in autonomous driving technology. Dr. E1, in the Enterprise E case study, had a strong desire to cultivate distinctiveness and ingenuity for future generations. Thus, Dr. E1 conducted a research study and concluded that it was a wise idea to invest in an autonomous business.

Secondly, the generation of ideas is based on the founder's specialised knowledge in a certain domain. Throughout Founder B1's time in the heating, ventilation, and air conditioning industry, it was noted that the HVAC system often accounted for around 50% of energy usage in buildings, as demonstrated by the example of Enterprise B. The merger of technology and artificial intelligence could effectively address the current deficiency in building infrastructure. Thirdly, the process of building a sustainable concept arose from recognising sustainable deficiencies and the individual's personal understanding of these deficiencies. The founders of Enterprise C studied manufacturing's 20% contribution to global carbon dioxide emissions. After learning the subject, the founders worked hard to design a complete system that gave industrial operators real-time energy performance ratings. Enterprise F expressed a consistent and ongoing worry about the problem of increased rates

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of gun violence in the founder's home country, South Africa. Due to rising gun violence in the United State, Founder F1 saw the possibility for technology to save lives in active shootings.

4.3. Sustainable Opportunity Recognition and Evaluation

Within the context of the deep-tech industry, the differentiation between sustainable opportunity recognition and sustainable opportunity evaluation is still unclear, as demonstrated by six case studies. The identification and evaluation of sustainable opportunities form the next phase in the sustainable entrepreneurship process. The identification and evaluation of sustainable opportunities are classified into two clear patterns: the examination of technologies to address environmental and/or social problems in conjunction with market values, and the prioritisation of sustainable values throughout the entire process.

The entrepreneur holds a strong belief in the potential of market size and the ability of favourable and differentiated technologies to drive firm growth. After an extensive study on sustainability concerns and evaluating the available products in the market, the founders of Enterprise B recognised significant shortcomings in the building sector. They proposed that these gaps could be effectively addressed by employing artificial intelligence technology. Furthermore, the prior entrepreneurial experience of the second co-founder was crucial in evaluating the long-term viability of the business. The founders of Enterprise F did a research study to determine the primary requirements of the sector and explored computer vision algorithms that may surpass human accuracy. Founder F2's previous business experience in artificial intelligence sales processes was demonstrated by the evaluation of Enterprise F.

The founders of Enterprise D suggested that artificial intelligence has the potential to significantly impact both the economy and society as a whole. This claim was based on their technological proficiency and extensive understanding of the sector. They believed that the specific breakthrough could significantly impact the trillion-dollar commercial transportation industry by enabling disruptive changes. In the case of the Enterprise A, Dr. A1 conducted a study on the recycling industry specifically, gaining extensive knowledge about the sustainability challenges it encounters. Dr. A1 then sought the counsel of two mentors who had distinct experience in the domains of industrial economics and industrial startups. The assistance provided by specialists was crucial in facilitating the ability to carry out a comprehensive analysis and evaluation of the economic viability of the proposal.

4.4. Venture Launch

In six case studies, when the entrepreneur has gathered sufficient information and skills to make an informed decision about starting a new business, the next step involves the process of exploitation. This stage is characterised by the founders legally launching the firm as a legal entity, complete with an official name and a sustainable vision and mission.

4.5. Sustainable Product Development

It has been observed that sustainable product development and new enterprise funding, formerly seen as happening one after the other, now occur concurrently inside the deep-tech industry. It is also the longest stage of the sustainable deep-tech entrepreneurial process.

The creation of Enterprise A commenced in 2014 with initial concepts. After thorough testing and technological advancements, the prototypes were publicly showcased for the first time in a controlled environment on a conveyor belt in early 2015.

Enterprise B's initial technology underwent a lengthy design phase that lasted almost two years to develop and commercialize the products. In 2017, Enterprise B dedicated its efforts to advancing technology. 2018 saw the introduction of an initial iteration of the testing software, followed by its implementation at two retail establishments. After the algorithm was successfully implemented, Enterprise B announced its innovative technology in May 2017. The main goal of this technology was to enhance the self-sufficiency of buildings, and provided environmental benefits.

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In 2014, Enterprise C developed an innovative app to locate and exploit energy conservation opportunities. After its 2015 introduction, two enterprises in the field immediately adopted the technology. Based on its successful partnership business model and technological advances, the company strengthens its engagement with many partners and enhances its technology infrastructure to satisfy changing needs.

Enterprise D spent its early years developing a beta autonomous driving system. Between 2018 and 2021, Enterprise D conducted several tests and experiments, including driverless trials at Quingdao port and along the Silk Road. After undergoing thorough testing and successfully implementing the technologies in commercial pilot projects, the company gained the ability to adopt a large-scale production approach in 2021.

Enterprise F invested heavily in 18-months AI training. Their efforts were focused on improving technological advancements that could reliably and consistently detect weapons in surveillance camera footage. Enterprise F introduced enhanced features in October 2019 to detect and identify threats and intrusions. These improvements included the incorporation of a highly advanced artificial intelligence system, which is well acknowledged for its exceptional ability to identify firearms.

Two years after launching the new venture, in April 2017, Enterprise E reached a significant milestone by introducing a driver attentiveness detection feature that incorporates video enhancement technology into the automotive industry, just two years after its founding. Following that, the company provided assistance to clients in improving fleet safety and continually adopting new features for collision prevention and safety automation, such as using artificial intelligence to generate predictive collision alarms.

4.6. New Sustainable Enterprise Financing

Financing a new firm is a crucial entrepreneurial activity, similar to the product development stage. It happened concurrently with the product development phase.

Enterprise A secured funding from numerous sources after achieving favourable outcomes with the initial prototypes. As of November 2022, Enterprise A had effectively obtained $91 million from Series C fundraising. Enterprise A allocated the funds to allow the expansion of its company operations and bolster its ongoing activities in global expansion.

Enterprise B secured $12 million in funding in April 2020. This funding was used to support the worldwide expansion of autonomous building technologies. Enterprise B reported in November 2021 that it had secured a $24 million investment. The purpose of this investment round was to facilitate the wider incorporation of artificial intelligence technologies in the built environment and to offer financial support for the company's upcoming phase of development.

Enterprise C received funds and non-equity investments from various in 2014 and 2015. Various investors provided €2.7 million in initial financing in 2017. An organization invested non-equity in Enterprise C in 2018. The corporation changed the technology to match each client's energy progress using the funds. In December 2019 and 2020, Enterprise C received almost 6.5 million euros in cash. The Enterprise C commenced its product development phase with the injection of external funding.

Enterprise D achieved a successful series B financing round in February 2021, raising a total of $200 million. Enterprise D plans to utilise the provided funds to accelerate the process of commercialising and implementing its autonomous mobility solutions. Subsequently, the company initiated a substantial expansion of its production activities and commenced the process of commercialising its technological advancements.

In 2018, Enterprise F secured pre-seed funding from various venture capital firms. In July 2019, Enterprise F obtained a capital of $2.2 million from a capital fund, and other investors. Enterprise F achieved a successful capital raise of $8 million through series A fundraising in April 2021. By allocating financial resources, the organisation focused on advancing its product line, leading to significant expansion and a commitment to enhancing driver safety worldwide.

Enterprise E operated largely on self-funding and contributions from the unpaid founder and leadership team in its first year. A venture capital provided $2.85 million in initial funding in

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September 2015. The startup raised $12 million in series A funding in April 2016. This financing contributed to the product development phase. The startup raised $159,000 in series B funding in July 2017. Capital helped the company create new products, hire more people, and improve leadership. The company's effective execution and continuous commitment to worldwide driver safety made these achievements feasible.

4.7. Scaleup Sustainable Enterprise

During the final phase of the sustainable entrepreneurial process, the startup enterprise achieved more assertive expansion and contributed to triple bottom line value. During the research of cross-case studies, companies repeatedly highlighted the need for integrating social and/or environmental values while discussing their plans for expansion, rather than emphasising profits. The corporations are anticipated to increase their profitability by prioritising the optimisation of their social and environmental responsibilities. Enterprise A demonstrated remarkable scalability by effectively detecting a significant number of over 66 billion objects, including more than 12 billion PET bottles. Enterprise B had a substantial impact on a total area of 100 million square feet in commercial buildings across 70 global sites since its establishment, effectively cutting total energy usage by a maximum of 25%, and reducing 20% - 60% carbon emissions. Enterprise C stated that by integrating consumer data into its knowledge base, there were possible energy savings of up to 15%. According to Enterprise D, the introduction of D's product had the potential to achieve a large 38% reduction in operational costs and a huge decrease in carbon emissions of around 1.1 million tonnes between 2021 and 2024.

In 2020, Enterprise F experienced a significant surge in its revenue, surpassing a growth of ten times. Consumer desire for improved security systems to reduce social unrest, gun violence, and pandemic safety concerns contributed to the significant growth. By 2019, Enterprise E had successfully penetrated the automobile markets in Asia, North America, and Europe. With real-time alerts, the technology advised drivers when they entered dangerous areas or lost focus. This reduced accidents by 50%. Since its founding, the firm has helped the largest commercial fleets reduce over 70,000 collisions, saving about $300 million.

5. Discussions

5.1. Technological Background

Dealroom's new report [16] indicates that projects in the field of deep-tech sometimes require lengthy research and development phases before a specific technology component can be effectively transformed into a marketable solution. These enterprises are frequently led by highly trained entrepreneurs who hold advanced degrees such as PhDs [17,37]. Entrepreneurs in this category might be described as engaging in knowledge-intensive entrepreneurship [38], which includes the domains of science, technology, and innovation [17].

The results of the analysis also suggest that a substantial number of entrepreneurs have engineering degrees, PhDs, or are currently involved in academic research. Moreover, a common pattern observed in the six case studies is the use of deep-technical solutions to tackle sustainability issues and the subsequent creation of business models focused on these scientific and technological progressions. The conclusion is substantiated by conversations with experts and a recent industry report [16]. After conducting a thorough investigation of six cases and existing theories, a proposition is developed as follows:

Proposition 1: Sustainable entrepreneurship in the context of deep-tech industry starts reflecting on entrepreneurs' technological knowledge and background.

5.2. Stage 1: Sustainable Idea Generation

Mets et al. [39] find that the entrepreneur's historical background, motivation, prior knowledge, and talents or capabilities influence idea generation. Perrini, Vurro, and Costanzo [40] found a relationship between social empathy and the capacity to produce inventive solutions. The

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entrepreneur's experience is crucial for recognising social needs, which then enables the discovery of opportunities and the formation of social entrepreneurship to address the associated demand [41]. According to Belz and Binder [9], a practical first step is to identify a social or ecological problem that the aspiring entrepreneur has personally or professionally encountered. Based on the individual's technological knowledge and capabilities, they can perhaps suggest a solution for the described problems.

This study demonstrates the integration of previous research findings. The examination of cross-case studies reveals that the definition of sustainable ideas in the context of the deep-tech industry is influenced by various aspects, such as personal interest in technology and scientific research, professional expertise, and the identification of gaps in sustainability. Therefore, a proposition is expressed as follows:

Proposition 2: Generation of sustainable idea in the context of deep-tech industry comes from personal interest in technology and scientific research, professional expertise, and the identification of sustainable gaps

5.3. Stage 2: Sustainable Opportunity Recognition and Evaluation

Four out of six case studies share similarities with traditional entrepreneurs, as the recognition of entrepreneurial opportunities in these cases is heavily influenced by previous knowledge [42–44] and the pursuit of personal advantages, particularly financial profit. When engaging in sustainable entrepreneurship, it is crucial to use a thorough cost-benefit analysis when making decisions, while also utilising a collective sense of connectedness to a social or environmental cause. Perrini et al. [40] argue that the evaluation of social opportunities requires a thorough examination of both the possible long-term effects and the economic viability of the project. The opportunity evaluation is crucial, as it allows individuals to not only recognise possible opportunities but also efficiently exploit them while meeting client needs. To evaluate sustainable possibilities, one must grasp the fundamentals and the broader social, environmental, and economic context [45].

The Enterprise C and Enterprise E case studies corroborate the conclusions of the previous study undertaken by Shepherd and Patzelt [6], and Matzembacher et al. [5]. Entrepreneurs often direct their attention towards sustainable gaps in the social and/or environmental landscape when they identify them as potential opportunities [6]. If the entrepreneur believes that the opportunity is both feasible based on their entrepreneurial expertise and self-confidence and desirable based on their motivational goals. Finding a solution to a problem can also create an opportunity to launch a new product or service into the market [5]. This includes both the client's needs and the competitive advantages [5].

Identifying and evaluating sustainable opportunities involves finding a balance between the potential of technology to generate social and/or environmental benefits and the economic advantages of long-term sustainability. Opportunities in deep-technology are typically less risky than those in strictly digital fields. When addressing a fundamental issue that has frequently gone unnoticed for decades, there will be a demand [10]. Given the limited availability of technology in the market and the complexity of technology, it is difficult to distinguish between opportunity recognition and evaluation.

The analysis results revealed that entrepreneurs' expectations about economic advantages and social and/or environmental benefits play a significant role. Therefore, a statement is expressed as follows:

Proposition 3: The recognition and evaluation of sustainability opportunities in the deep-tech industry arise from finding a balance between social and/or environmental outcomes and economic benefits, with the aim of creating enduring value for sustainability.

5.4. Stage 3: Venture Launch

After gathering sufficient information and experience, the entrepreneur proceeds to launch a new enterprise. In contrast to the first two stages of the sustainable entrepreneurial process, which mostly focus on integrating innovative technologies, this specific step entails integrating a sustainable

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vision and mission into a new business. The founders intentionally integrated the environmental and societal impacts of deep-tech as both the goal and approach to meet sustainable requirements, creating a unique market for themselves.

At this stage, the entrepreneur begins to put their ideas into action and takes the required measures to create a new business venture [46]. The outcome of the venture launch stage involves the establishment of the enterprise, which can also be seen as the act of taking advantage of sustainable chances [39]. Sustainable entrepreneurs differ from traditional entrepreneurs in that they do not prioritise profit as their main objective [47]. Instead, they strive to create a new organisation that symbolises a goal focused on sustainability [40]. The examined case studies also place considerable emphasis on making a lasting and environmentally friendly impact on their goals and aspirations. Therefore, the fourth proposition is stated as follows:

Proposition 4: Venture launch occurs when a sustainable vision and mission come together to develop a new enterprise that aligns with those principles.

5.5. Stage 4.1: Sustainable Product Development

In contrast to prior studies [5,9] which suggest that product development typically occurs before the exploitation of sustainable opportunities, our analysis of six case studies reveals that in the context of deep-tech, the stage of sustainable product development actually took place after the companies were established.

The case studies indicated that businesses allocate significant effort and resources to this phase, particularly within the initial one to three years of the launch. Organisations tend to continuously upgrade, test, and introduce newer versions of their technology instead of stopping at the initial stage of creation. The research conducted by Dimov [48], Corbett [49], and Vogel [46] provide more evidences that the product development stage is marked by a significant amount of iteration and dynamism. This stage involves acquiring knowledge in unforeseen situations and as a result of experimentation. The sustainable product development stage targets optimizing the capabilities by developing the specific mechanisms of the innovative model variation [45]. The assessed potential is welcomed and subsequently enhanced into a comprehensive business and product strategy [9,45]. This phase also provides the opportunity to create preliminary prototypes and showcase them to customers and stakeholders for beta-testing [39,45], conduct pricing strategy experiments, or refine, shape, and improve the business concept [50]. Within the deep-tech industry context, the process of product development encompasses the development of prototypes that feature adequate functionality, along with conducting market research and collecting feedback. This process finally culminates in achieving market readiness [51,52].

The structure of the fifth proposition is as follows:

Proposition 5: Sustainable product development in deep-tech industry necessitates significant time and financial resources, particularly in relation to the development, adoption and implementation of deep-technologies. This phase also encompasses the testing and trial of beta versions.

5.6. Stage 4.2: New Sustainable Enterprise Financing

The funding of sustainable new businesses takes place simultaneously with the stage of developing the product, as a result of the intricate characteristics of deep-technologies. Ensuring adequate funding is essential to develop and subsequently bring the technology to market [53]. The funding of a sustainable start-up is a crucial phase in an entrepreneur's quest to develop technology goods and services that prioritise long-term value creation rather than just revenue. Similar to the product development phase, prioritising the importance of social and environmental values will help achieve feasible and sustainable growth.

Financing a new firm is a crucial entrepreneurial activity, similar to the product development stage [54,55]. The expansion of new enterprises relies on the establishment of their capital structures at the beginning of their existence and the ongoing financing of innovative activities throughout their

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lifespan [56]. Grants, donations, and loans are needed when a company lacks commercial revenue or reserves during a certain stage of the entrepreneurial process [57,58].

The implementation of sustainable entrepreneurship is often hindered by its substantial expenses in product development, leading individuals to continue with traditional entrepreneurship that emphasises financial profits rather than environmental preservation and societal values [59]. The increase in net capital inflows into sustainable enterprises and funds attributes to the value placed on sustainability [60–63]. None of the social entrepreneurs who participated in the survey performed by Shaw and Carter [47] had a primary goal of financial profit. Startups that prioritise sustainability are expected to receive a significantly greater amount of investment. This is because their enhanced valuation is influenced by their positive impact on communities and the environment.

In the research case studies, all businesses prioritised technology innovation to address sustainability challenges over profitability. Hence, securing external finance is vital for sustaining a company's research and development initiatives as well as ensuring its long-term operational viability. The use of deep-technology and a firm dedication to sustainability give the startup a unique identity, allowing it to achieve a significant position in terms of funding. The sixth proposition is organised as follows:

Proposition 6: The financing of sustainable new ventures is a critical stage for entrepreneurs to build technology products/services and achieve sustainable values, rather than focusing solely on profitability.

5.7. Stage 5: Scaleup Sustainable Enterprise

In the last stage of the sustainable entrepreneurial process, startups strive to achieve more decisive expansion. At this stage, the company reaches a level where it begins to generate profitable sales or reaches the point where expenses are equal to revenues. Belz and Binder [9] state that sustainable firms participate in the creation of new sustainable market sectors or enter current ones. Sustainable firms are expected to improve social and community networks, cultural and environmental conditions, human rights, economic development, education, citizenship, and health [5]. This sets them apart from traditional entrepreneurs. Scalability, within the realm of sustainability, refers to a company's efforts to widely spread a sustainable solution, maximising social transformation and progress [40]. The interaction of sustainable entrepreneurship with entrepreneurial processes, market and industrial revolutions, and societal and environmental developments leads to numerous levels of impact [64]. This alignment enables the attainment of analysis results across the case studies. The seventh proposition is formulated as follows:

Proposition 7: Sustainable enterprise scaling up when the entrepreneur generates societal and/or environmental benefits with the aim of achieving economic gains.

5.8. A Sustainable Entrepreneurial Process Model of Deep-Tech Entrepreneurship

The aim of this article is to investigate the progression of sustainable entrepreneurs as they transition from startup ventures to scaleup enterprises within the context of deep-tech. The process model offers innovative perspectives on the process as a sequential series of events, comprising six fundamental activities: (i) Sustainable idea generation; (ii) Sustainable opportunity recognition and evaluation; (iii) Sustainable opportunity exploitation; (iv.i) Sustainable products/ services development; (iv.ii) New sustainable enterprise financing; and (v) sustainable enterprise scaleup. In contrast to prior research on the process of sustainable entrepreneurship, sustainable entrepreneurial opportunities within the context of the deep-tech industry come from entrepreneurs' interests and knowledge of emerging technologies that can be leveraged to address current sustainability challenges. Figure 1 illustrates the sustainable entrepreneurial process in the deep-tech industry.

The process begins with the conceptualization of entrepreneurial ideas and the identification of opportunities, in which entrepreneurs frequently prioritize technological interventions to tackle sustainability issues. The entrepreneurial opportunity recognition and evaluation stage lies in achieving a harmonious equilibrium between technological progress, and environmental, social, and economic prosperity while simultaneously fostering the creation of novel avenues for business

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development. The process is intricate, necessitates substantial resources, and entails inherent risks. Entrepreneurs frequently seek counsel from industry experts or collaborate with partners in order to effectively navigate the complexities associated with market entry and the successful realization of their ideas.

The stage of sustainable opportunity exploitation entails the integration of a sustainable vision and mission into a nascent enterprise, with a particular emphasis on the significance of environmental and social values. The trajectory of a technology startup operating within the deep-tech landscape is intricate, necessitating entrepreneurs to develop comprehensive frameworks and tools to effectively implement a robust business model and adequately prepare for financial backing and expansion. The adoption of a sustainable values framework represents a prudent strategy that has the potential to enhance entrepreneurs' ability to attract customers, investors, and government backing.

The stage of a startup encompasses two concurrent activities: sustainable product development and new sustainable enterprise financing. The development of sustainable deep-technologies necessitates an intricate and intensive research and development procedure, wherein the progression of products from inception to market readiness spans multiple years. The expansion of deep-tech enterprises follows a prolonged trajectory, and incorporating a focus on social and ecological values can play a role in facilitating feasible and enduring growth. Financing for sustainable enterprises occurs concurrently with the product development process, with a dominant emphasis on sustainability.

The successful scaling up of sustainable enterprises necessitates the acquisition of "patient" capital as a result of the complex nature of technology and the regulations inherent in the scale-up process. These companies are subject to significant scrutiny to demonstrate that their research efforts can yield substantial financial returns, as supported by robust scientific investigation. Nonetheless, the process of commercialising scientific discoveries is a venture apprehensive with considerable risks, necessitating the presence of "patient" capital. This form of capital demands that both entrepreneurs and investors exercise patience as they await the realisation of financial gains.

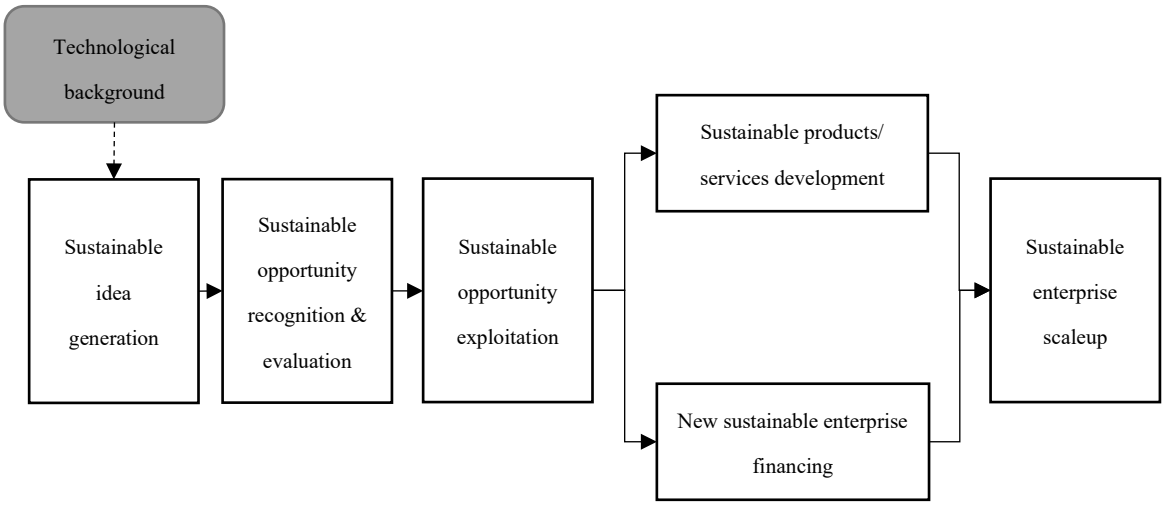

Figure 1. Sustainable entrepreneurial process in the deep-tech industry. Source: The authors.

6. Conclusions

6.1. Theoretical and Practical Contributions

The literary contribution entails offering an all-encompassing comprehension of the sustainable entrepreneurial process, which fills the voids indicated by Choi and Gray [8], Belz and Binder [9], Matzembacher et al. [5]. These gaps refer to a lack of information in the field of sustainable

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entrepreneurship, as well as the need for studies on how entrepreneurial activities contribute to the Sustainable Development Goals [65]. The study presents a novel and comprehensive theoretical framework that provides knowledge of the sustainable entrepreneurial process in the deep-tech sector. This work offers essential insights and serves as a foundation for future research to tackle unresolved difficulties at different stages of the process. It accomplishes this by identifying and addressing significant gaps in the existing literature [66,67].

Furthermore, this study strengthens the connection between entrepreneurship, sustainability, and deep-technologies. It provides insights for sustainable entrepreneurs who are now engaged in or considering involvement in the deep-tech sector linked with deep-tech industry, taking into consideration the significant presence of deep-tech sustainable startup companies. Technology expertise and interests possess the ability to effectively address social and/or environmental problems, thereby serving as catalysts for the creation of entrepreneurial opportunities. The entrepreneurial process highlights the significance of the technological aspect, particularly during the first stage. Finally, it is crucial for policymakers to develop laws and legislation that offer assistance to start-ups and investors in the deep-tech sector. This assistance will empower them to demonstrate resilience in their technical progress and make substantial contributions towards sustainable development.

6.2. Limitations and Directions for Future Research

The article, as anticipated, has essential limitations. The article's most significant contribution lies in the utilisation of the qualitative research approach to develop the deep-tech sustainable entrepreneurial process model. The choice of case studies was limited to startups in developed countries. Therefore, there is a possibility to study the sustainable entrepreneurial process in emerging or developing countries. Moreover, the use of internal and external secondary data in qualitative research might lead to incomplete findings and restricted analytical viewpoints. The opportunity for future study resides in the ability to undertake either data-driven or quantitative research to investigate the entrepreneurial process of individual entrepreneurs and compare it with the suggested process model for validation.

Furthermore, the article expects to shed light on the process by which sustainable entrepreneurs successfully shift from the initial startup phase to the subsequent scaleup phase. While the research method helped to gather relevant evidence about the development of sustainable entrepreneurship, it did not provide a sufficient explanation for the fundamental reasons behind this process. Future academics have the opportunity to investigate each stage of the sustainable entrepreneurial process, as well as the business model canvas, tactics, and internationalization of deep-tech sustainable businesses.

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