

Review

Sustainable Emerging Technologies: Battle for Dominant Design

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Abstract: When sustainable emerging technologies (SETs) enter mainstream markets, a battle unfolds between pioneers and incumbents to establish the new dominant design. The purpose of this article is to explore the key factors that determine the outcome of such technological battles. Based on an extensive literature review and drawing on insights from behavioral economics, five research hypotheses are proposed to examine whether the final outcome depends on the discontinuous or disruptive nature of the SET—specifically, whether its entry into the mainstream market is direct or indirect—and on whether incumbents perceive it as a threat or an opportunity. The article also aims to clarify the prevailing confusion surrounding the concept of disruptive technology by proposing a refined definition that builds upon and complements previous ones. From an academic perspective, the contribution lies in incorporating behavioral economics into the analysis of technological battles, thus opening new avenues for research, as well as offering a definition of disruptive technology that could help standardize research frameworks in this field. From a managerial standpoint, this article supports innovation managers in understanding the introduction and expansion of SETs, enabling them to develop more effective strategic responses.

Keywords: sustainable emerging technologies; direct/indirect attack; disruptive technology; discontinuous technology; dominant design; behavioral economics



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1. Introduction

The global challenges related to climate change, depletion of natural resources, and pollution have driven the unstoppable emergence of sustainable emerging technologies (SETs). Given the growing concern over the planet's limited ecosystems and resources, there is an increasing demand for innovative solutions that reduce environmental impact, optimize resource use, and promote circular and low-carbon economies [1].

Every time a sustainable energy technology (SET) is introduced into a mainstream market, a process of 'creative destruction' [2] begins, in which the new sustainable technology eventually displaces 'current' dominant design (or technology in use) and becomes the 'new' dominant design [3]. The two main actors in this process are the pioneers, who introduce the SET, and the established firms (incumbents), who exploit the current dominant design. For some time, both will compete to develop the SET design variation that becomes the new dominant design [4,5]. This competition is intensified by the increasing pressure on companies to align with the Sustainable Development Goals (SDGs) of the United Nations 2030 Agenda [6].

Despite the abundant academic research on these types of technological battles, it does not always go in the same direction. While some empirical studies support the pioneers as the winners due to their first-mover advantage [7–10], other studies point to

the incumbents due to the advantage that their resources and experience give them to co-opt innovation and establish the dominant design [11–16]. The research gap caused by this lack of unanimity motivates this work, whose main objective is to determine why two opposite outcomes can coexist concerning the same process. To this end, relying on several exhaustive reviews of the literature [4,5,17–22], we identify those factors that can be decisive in the development and outcome of technological battles. Then, analyzing these factors through the lens of behavioral economics [23,24], and in combination with the traditional approach of technological strategy [7,8,25–30], we propose five hypotheses about which actor—the pioneers or the incumbents—is most likely to establish the ‘new’ dominant design. These hypotheses (or conjectures), based on real cases analyzed and published in high-impact scientific journals, as long as they are not refuted [31,32], serve to determine whether the contradictory results regarding the winner in the battle for the ‘new’ dominant design are random or respond to some systematic justification.

Among those factors identified, the nature of the introduced SET—discontinuous or disruptive—stands out as crucial [33]. In this regard, the literature analysis has allowed us to detect a second research gap. While there seems to be unanimity on when technology is discontinuous [7,15,27,34–36], there is still considerable academic and business confusion surrounding the concept of disruptive technology [17,19,22,35,37–39]. Although there are diverse and varied conceptualizations that can be found [8,40–45], none of them covers all the types of technological disruptions that can occur. It is widely accepted that conceptual ambiguity prevents the academic advancement of a theory, while it impedes entrepreneurial good decision-making [46]. Therefore, a second objective of this paper is to propose a definition of disruptive technology that encompasses and completes previous ones, without contradicting them. This allows us to cover the entire possible spectrum of technological disruptions. Starting from Christensen’s original framework and the subsequent refinements made by other researchers, we develop a definition of disruptive technology in terms of its necessary and sufficient conditions. For the sake of similarity and clarity, we do the same with the definition of discontinuous technology.

In short, although there is a substantial body of research on disruptive innovation and battles for the dominant design, significant inconsistencies persist in terms of findings and conceptualizations. The lack of a theoretical model that systematically integrates business perception in the development of these processes, along with the conceptual ambiguity surrounding disruptive technology, limits both theoretical development and the effectiveness of strategic decision-making in organizations. This situation not only hinders the comparison of results across studies but also prevents the generation of cumulative and applicable knowledge. Addressing these shortcomings is particularly relevant in a context where technological disruption cycles are becoming faster and more complex, demanding more precise and predictive conceptual tools from companies and researchers alike. Our work responds to this need by proposing an integrative conceptual framework based on behavioral economics and technology strategy, as well as an operational definition of disruptive technology that reduces current terminological fragmentation.

The contributions of this work are both academic and business-related. From an academic perspective, the proposed integrative conceptual framework helps reconcile the findings of seemingly contradictory currents, facilitates the advancement and standardization of research on dominant design, and allows for the identification of new areas of research. Furthermore, the proposed definition of disruptive technology, which refines and complements the previous ones, reduces the existing conceptual ambiguity in this regard and eliminates obstacles to the advancement of theory.

From a business perspective, this article provides companies—whether pioneers or incumbents—with a deep understanding of the context in which the battle for the

dominant design takes place, enabling them to develop effective technological strategies that help balance the pursuit of competitive advantages with growth and sustainability. The formulation of our hypotheses aims to determine that the perception of threat or opportunity posed by an SET upon entering the market is a decisive factor in the outcome of the battle. They also seek to determine that this perception is directly related to the nature of the SET. Thus, a discontinuous SET, by directly targeting the mainstream market, is perceived as a threat by incumbents, prompting them to react quickly and invest heavily, thereby increasing their chances of winning the battle. Conversely, a disruptive SET, being initially commercialized in an alternative market and not directly attacking the main market, is perceived merely as an investment opportunity. As a result, incumbents will not react in time and will lose their chance to win the battle. The corroboration of these results provides companies with valuable information on how they should act in the fight for the dominant design of an SET if they want to succeed.

The study's structure to achieve these objectives is as follows. First, we delineate and compare SETs, classifying them as disruptive or discontinuous. Then, we analyze the battle for the new dominant design between pioneers and incumbents, exploring the decisive factors in the different scenarios that may arise. Finally, we present conclusions, academic contributions, and implications for business practice. We also identify potential lines of future research.

2. Literature Review, Definitions, and Hypotheses

This section analyzes, on the one hand, the discontinuous or disruptive nature of SETs, and on the other, how that nature is decisive in the development and outcome of battles for the dominant design. Both studies are based on an analysis of the literature conducted in three stages. First, a selective review of already published systematic reviews is conducted. In this step, eight systematic reviews published between 2010 and 2023 are identified and analyzed. These reviews focus on the conceptualization, processes, and factors influencing disruptive innovation and the consolidation of dominant design (see Appendix A, Section A1). Second, to complement the perspectives gathered from these reviews, seventeen additional articles—both theoretical and empirical—are selected (Appendix A, Sections A2 and A3). These include new conceptual frameworks, case studies, and recent analyses on disruption dynamics and dominant design. Finally, a conceptual synthesis of all the reviewed articles is carried out, followed by an interpretative analysis aimed at identifying research gaps, conceptual tensions, and opportunities for theoretical development.

This process culminates in the identification of the two challenges addressed in our article. Their analysis and the subsequent development of hypotheses are carried out by combining the traditional theoretical framework of technological strategy [7,8,25–30] with selected principles from behavioral economics [23,24]. All of this allows us to ground our proposed research model in an updated and representative background and to ensure a rigorous and well-reasoned approach.

2.1. Discontinuous vs. Disruptive SETs

In discussing the discontinuous and disruptive nature of SETs, we speak only of radical sustainable product innovations; radical process innovations, service innovations, innovations in different functional areas, business model innovations, and social innovations are not included.

2.1.1. Discontinuous SET

Any comparison of product performance implicitly considers a common metric by which the value will be assessed [47]. Every product possesses several technological dimensions of value, each with its own performance metric. The dimension that represents the performance metric currently valued by the mainstream market and the main source of motivation for consumers to buy the product is known as the primary dimension or the ‘order-winning criterion’ [48]. As the most important basis for performance, it also becomes ‘the basis for competition’ [49]. For correctly priced products, a superior primary dimension is a good sales argument, providing at least a temporary competitive advantage. The remainder of the dimensions and performance metrics that consumers expect from the product are known as secondary dimensions or ‘order-qualifying criteria’ [48]. These technological dimensions cannot be used as a sales argument, but they represent additional restrictions; if the product does not meet these criteria to a satisfactory standard, the consumers will not buy it.

Sometimes, a pioneer introduces an SET into the mainstream market that, compared to the current dominant design, entails a drastic order-of-magnitude improvement in the performance metric of the order-winning criterion. This is not an ‘incremental change’ sustaining innovation, but rather a ‘major breakthroughs’ sustaining innovation resulting from a significant leap forward in the knowledge that underpins the order-winning criterion [8]. As a result, the SET offers superior performance relative to the current dominant design, leading mainstream market consumers to perceive it as better and switch to it without hesitation.

Typically, at the time the SET enters the market, the current dominant design still achieves a superior performance in the order-winning criterion, but with little remaining potential for improvement. In contrast, the SET intrinsically possesses greater future technical potential [50] and will soon outperform the current dominant design [7,27]. Nevertheless, in some cases, the SET may achieve a better performance for the order-winning criterion from the outset [51]. In either case, due to its current or potential superiority in the order-winning criterion, the SET will displace the current dominant design. Consumers’ priorities remain the same, but the new technology satisfies them more effectively, leading them to abandon the current dominant design and causing a technological discontinuity in the mainstream market [15,34,36,52,53].

An example of a discontinuous SET that is characterized, in its origins, by a worse performance than the current dominant design, but with much higher potential for improvement, is artificial ice technology. When artificial ice technology was first introduced to the market, it initially failed to achieve a performance comparable to the traditional dominant cooling technologies, which were primarily based on compressors. However, artificial ice technology had enormous potential for improvement. As technology advanced, its capacity to create more efficient and sustainable solutions in terms of energy consumption and emissions reduction grew enormously, as did its ability to reduce operational costs. This made it a viable alternative to the more expensive and pollution-emitting traditional solutions, which it ultimately displaced [54]. An example of a discontinuous SET which has always been characterized by better performance than the current dominant design is LED technology. Since its introduction, it has represented a radical improvement in performance, energy efficiency, durability, and operating costs compared to incandescent and fluorescent lighting technologies. Thanks to these advantages, as well as other economic and environmental incentives, this technology quickly gained acceptance worldwide and created a discontinuity in the market, almost completely replacing incandescent bulbs and largely displacing fluorescent ones in the industrial, commercial, and residential sectors. Today’s consumers perceive LED lighting as superior, not only due to its energy efficiency

and lifespan but also because of the associated economic savings and lower environmental impact. In fact, many countries have banned or reduced the production of incandescent bulbs, and LEDs have become the dominant technology in the lighting industry [55]. Both artificial ice and LED lighting technologies represent a huge leap forward, rather than a simple evolution of existing technologies.

To summarize above, we define discontinuous SETs in terms of necessary and sufficient conditions. The necessary condition is that a discontinuous SET achieve an order-of-magnitude improvement in the current order-winning criterion; that is, in the technological dimension most valued by the consumers in the mainstream market. A discontinuous SET does not alter the competitive base or displace the performance metric of the current dominant design, but it exhibits a much higher performance (real or potential) according to this metric. The sufficient condition is that the discontinued SET is commercialized from the beginning in the mainstream market; that is, for incumbents, it represents a direct attack.

2.1.2. Disruptive SET

A disruptive technology is difficult to define. Since its origin, the term disruptive has been used to define a wide variety of concepts, but no full consensus has been reached. Therefore, before delimiting its definition, we explain the evolution of the term and why it might be a source of confusion.

Evolution of the Term Disruption

Originally, disruption described a ‘process’ whereby a smaller company (disrupter) with fewer resources could successfully challenge established firms [56]. The term was coined by Christensen, who initially focused primarily on technological innovations and explored how new technologies came to surpass seemingly superior technologies in the market. Christensen [8] stated, ‘Disruptive technologies are typically simpler, cheaper, easier, and more convenient than dominant technologies’. When they succeed, disrupters move from the low end of the market to the mainstream, eroding the incumbents’ market share and, ultimately, their profitability. Later, Christensen and Raynor [57] replaced the term ‘disruptive technology’ with ‘disruptive innovation’.

With the term ‘disruptive innovation’, the application of the theory widened to include not only technological products but also services and business model innovations, such as discount department stores, point-to-point airlines, and online business education. Consequently, it could be said that disruptive innovations require new business models, but not necessarily technological breakthroughs [58,59].

While it is true that the focus of ‘disruptive innovation’ has widened the scope of disruption theory [60], it has done so at the cost of obscuring the understanding of the product’s performance at a technological level and its relationship with the competitive advantage [49]. Markides [38] argues that disruptive technology is a completely different phenomenon from business model disruptive innovations: They have different origins, produce different competitive effects, and require different answers. In this study, we only refer to disruptive technology.

Christensen and Raynor [57] also differentiated between two different disruptions: ‘Low-end disruptions’, in which the disrupters target unserved low-end consumers by offering an inferior technology, subsequently encroaching on incumbents’ high-end consumers when the technology has developed sufficiently to meet those consumers’ needs, and ‘new-market disruptions’, wherein disrupters create a completely new market (niche) from which, over time, they can expand into the incumbents’ market. Subsequently, a complementary framework classified new-market disruptions [40] as ‘fringe-market low-end encroachment’ (where the consumers’ needs are incrementally different from those

of current low-end consumers) and ‘detached-market low-end encroachment’ (wherein consumers’ needs are dramatically different from those of current low-end consumers). Similarly, recent streams of research have attempted to broaden the definition of ‘disruptive innovation’. However, to create the theory of disruptive innovation [8,56,60], Christensen has adhered closely to his original conceptualization [61].

Despite the advances in conceptualizing ‘disruptive innovation’ and explaining its drivers and challenges [17,19,22,56], the term still has multiple uses and is often treated as synonymous with ‘disruptive technology’ [45].

Although Christensen’s contributions are useful for establishing a definition of ‘disruptive technology’, they cannot be generalized to explain all kinds of technological disruptions. This is because Christensen positions these technologies as a process that evolves toward the mainstream market [58]. His contributions have two important restrictions, one related to the range of disruptive technology and the other to the pioneers of the disruption. In most cases, these restrictions are at odds with the real scenarios. The first restriction is to consider that disruptive technologies are those that initially take root in simple applications at the low end of a market or in a new market (niche), and then relentlessly move ‘up market’ [19,56,57,62–64]. By delimiting disruptive innovation as a ‘process’ that evolves from the low end of the market or a new market (niche) to the mainstream market, Christensen et al. [62] consider Uber to be a non-disruptive technological innovation. However, other academics have identified Uber as a good example of a technology that disrupts the market [41,65]. The second restriction is to consider that only small, resource-poor companies that can challenge incumbents successfully can launch disruptive technologies. According to this approach, a firm’s competitive advantage is generally deemed non-sustainable because the pioneers will defeat the incumbents unless they set up a separate and autonomous business unit, which seldom occurs [8]. However, following the strategic management approach, incumbents can use their resources and capabilities to maintain (and improve) their competitiveness. As the disruption affects operations and competitive strategy, incumbents may initiate it deliberately and gain a sustainable competitive advantage as a result [45]. It is difficult to accept that incumbents do not participate in disruptions [66,67], especially when they are the so-called ‘FAANG’ firms.

In short, depending on which of the contributions an author’s research is based, ‘disruptive technology’ may be more narrowly or broadly defined; there is also variance in the type of innovative companies that are considered disruptive [45,68].

After observing the evidence, we believe, and thus propose, that it is not only resource-poor small companies that can launch technological disruptions, but that large incumbents can do the same. Likewise, they can take root not only in low-end or new markets, but also in high-end markets, developing countries, or even the mainstream market [41,45,49,69–71]. This leads us to consider disruptive technology not as a ‘process’, but as a ‘result’. Based on the above, in the following subsection, we define the concept of disruptive technology, presenting it as an extension of Christensen’s original concept and focusing on integrating all real scenarios that may occur in practice.

Definition of Disruptive Technology

In its original conception, Christensen described disruptive technology as an emerging technology that achieves superior performance in some of the order-qualifying criteria of the current dominant design (not in the order-winning criterion), and it is introduced into a new (niche) or a low-end market. In the order-winning criterion, this emerging technology fails to meet the minimum performance level required by the mainstream market consumers and is thus rejected [8,57]. The incumbents also refuse to adopt it because (a) it is only suitable for a limited range of consumer applications which are

not valued by their existing consumer base, (b) there is uncertainty regarding which of the different technological variations will succeed, and (c) the new technology has low profitability. Additionally, this technology's potential for improvement is ill defined, and there is always the risk that it will remain disconnected on an 'application island' [72]. For these reasons, the pioneer seeks a group of consumers outside the mainstream market whose needs can be met by the emerging technology. These consumers assign positive value to the new non-standardized dimensions of the value provided by the emerging technology at a certain performance threshold. Consequently, this technology offers a targeted value proposition for the consumers of the niche or low-end market [57].

During its commercialization in the niche or the low-end market, the pioneer continues to develop the emerging technology. Eventually, the improvements achieved in the order-winning criterion will exceed the performance demanded by the mainstream market [8,62,69]. At that time, the pioneer will introduce the evolved emerging technology into the mainstream market [17,40,73]. As this technology satisfies consumers' primary needs, one of its secondary dimensions (or order-qualifying criterion) begins to catch their attention [74], so much so that the mainstream market will come to prioritize this order-qualifying criterion and make it the 'new' order-winning criterion. In other words, the basis of competition in the mainstream market shifts from the primary dimension of value to a secondary dimension [8,37,67,68,75,76]. This change in priorities implies that consumers abandon the current dominant design in favor of the new technology [8,56], provoking a technological disruption in the market. Therefore, disruptive technology changes the basis for competition because it alters the performance metrics which inform consumers' preferences. That is, disruptive technology changes consumers' expectations [37,38,49,69]. Such technology is referred to as 'potential disruptive technology' during its commercialization in the niche or low-end market [18,35]; upon entering the mainstream market, it loses its 'potential' qualifier and, thereafter, can be classified as 'disruptive technology'.

An example of an SET that followed this process is photovoltaic solar energy [77]. Initially considered a marginal emerging technology due to its high cost and low efficiency, in the 1970s and 1980s, its application was limited to specific niches such as special satellites and rural communities without access to the electrical grid. At that time, solar energy was unable to compete with traditional energy sources (coal, gas, nuclear) in the mainstream energy market because it did not meet the 'order-winning criterion', which was the generation of massive amounts of cheap energy. However, consumers began to value its non-standard features such as grid independence, the ability to operate in remote locations, and its low environmental impact. Thanks to technological advances and economies of scale, solar panels have become progressively more efficient, meeting and even exceeding mainstream market expectations—so much so that, today, solar energy competes directly with traditional energy sources, often available at lower costs and offering a smaller environmental footprint. Consumers and governments have begun to prioritize values such as sustainability, carbon emissions reduction, and energy independence, which have transitioned from 'order-qualifying criteria' to the new 'order-winning criterion', thereby shifting the base of competition in the energy market.

Therefore, there is empirical evidence that confirms the process described by Christensen and other researchers; however, there also is evidence that provides examples of disruptive technologies rooted in a high-end market, an emerging market, or even the mainstream market itself.

For example, there are potential disruptive technologies that have been superior to the dominant design since their conception. These technologies provide better performance but at higher prices [78], so they start the commercialization process in a high-end market [17,35,42,51,69,79]. In these cases, the price becomes the basic order-winning criterion,

and the potential disruptive technology facilitates a price well above the maximum level accepted by the mainstream market. Once the price is set below the maximum level, the mainstream market begins to value some of the other secondary value dimensions that will eventually become the ‘new’ order-winning criterion [80].

An example of this is electric vehicles, which initially targeted the high-end market but are progressively disrupting the mainstream market [81]. These vehicles, led by companies like Tesla, began attracting the attention of high-income consumers who valued sustainability, performance, and exclusivity, regardless of the high price. Over time, companies began improving battery technology, reducing costs per kilowatt-hour, and increasing the range of electric vehicles. These changes, combined with investment in charging stations and government incentives, allowed electric vehicles to enter the mass market. At this point, the ‘order-winning criteria’ changed from price, reliability, and design to sustainability, energy efficiency, and long-term operating cost savings. Although electric vehicles are not yet the dominant design, the trend towards the electrification of mobility, driven by technological, economic, environmental, and regulatory factors, positions them as a strong candidate for total disruption of the automotive industry in the future.

In other cases, the determining factor of disruption is external to the company, including changes in the regulatory environment, etc. One example is electric furnace technology for steel production [82]. Steelmaking has long relied on traditional electric arc furnaces that use coal, generating significant CO₂ emissions. However, the increasing environmental regulations and global decarbonization goals have led many manufacturers to replace traditional furnaces with electric induction ones, contributing to a cleaner and more energy-efficient industry.

Likewise, disruption can take root in a ‘reverse technology’—that is, a technology initially marketed as potentially disruptive in a developing country [43,44]. When that technology enters advanced markets, it can threaten the higher-end and more costly version of the product. An example of reverse sustainable technology is the development of portable solar cookers [83], which were initially designed for rural communities in developing countries, where access to modern cooking fuels was unavailable. In addition to being an affordable solution for low-income populations, by using solar energy and eliminating the need to burn wood, coal, or kerosene, these cookers help reduce deforestation and the emission of harmful gases. This sustainable method of outdoor cooking began gaining popularity in developed countries, as it was deemed ideal for campers, hikers, and people looking for eco-friendly alternatives to reduce their carbon footprint. Their efficient, sustainable, and portable design positioned these cookers as a more attractive alternative to gas or charcoal grills and a challenge to the more expensive and complex solar cooking technologies developed in advanced countries.

Finally, disruption can also take root in the mainstream market [45,79]. This occurs when a secondary performance dimension of the current dominant design has the potential to become the ‘new’ order-winning criterion and displaces the ‘current’ one. In this case, one of the incumbents can detect that potential and act to change the basis of the competition. For example, traditional plastic packaging manufacturers initially focused their competitive advantage on the durability and protection of the contents of these containers. Over time, some manufacturers realized that all companies in the sector more than adequately met both dimensions, so they no longer represented a differentiating factor for the consumer. Consequently, these visionary manufacturers, seeking to change the basis of competition, focused on a secondary value dimension that, given current societal demands, could become the new winning criterion. While maintaining the durability and protection of packaging contents deemed satisfactory by the mainstream market, they began to focus on environmental sustainability, developing biodegradable packaging from renewable

materials [84]. In this way, a secondary dimension previously considered a qualifying criterion became the new winning criterion, and, in turn, the current winning criteria became qualifying criteria.

Taking all of the above into account, and just as we did with the discontinuous SET, we define disruptive SET in terms of necessary and sufficient conditions as follows. The necessary condition is that disruptive SETs displace the technological dimension prioritized by the consumers of the mainstream market and turn a secondary technological dimension into the new order-winning criterion. Therefore, a disruptive SET, unlike a discontinuous SET, changes the basis for competition and performance metric of the current dominant design. The sufficient condition is that, before attacking the mainstream market and causing the disruption, the potential disruptive SET is commercialized in some niche, segment, or market; that is, for incumbents, it represents an indirect attack.

Table 1 compares discontinuous and disruptive SET and delimits their scope.

Table 1. Discontinuous versus disruptive SETs.

Current Competition		Introduction of a Sustainable Emerging Technology (SET)			
Contenders	Incumbents	SET Pioneers			
Technology	Current dominant design	Discontinuous SET	Potential disruptive SET	→	Disruptive SET
Market	Mainstream market	Mainstream market	New market (niche) Low-end market High-end market Developing country market Mainstream market	→	Mainstream market
Basis for competition	Order-winning criterion	Drastic order-of-magnitude increase in the order-winning criterion	Order-winning criterion	→	Order-qualifying criterion on mainstream market: New order-winning criterion
		Competence-enhancing technology	Competence-enhancing/destroying technology		Competence-destroying technology

2.2. Battle for the New Dominant Design

Independent of whether the SET is disruptive or discontinuous, a battle breaks out in the mainstream market between the pioneer and the incumbents. The winner is the contender who succeeds in creating the new dominant design that will replace the current one.

In the ensuing battle, incumbents always have an advantageous position compared to the pioneer. A ‘new’ dominant design initially requires a product radical innovation, followed by a radical process innovation [27,85], which enables large-scale commercialization in the mainstream market [86,87]. The economies of scale achieved through radical process innovations strongly support dominant designs [88]. In this sense, incumbents are better able than pioneers to achieve product–process co-specializations. Incumbents possess large economic resources and abundant transferable technological capabilities [89]; they also have extensive accumulated experience in the mainstream market [90], a good corporate image [13], and possess necessary complementary assets (e.g., manufacturing capability and distribution systems) [91]. Pioneers generally need time to develop the capabilities required to compete in the mainstream market. The skills successfully deployed to satisfy early adopters do not guarantee that the product will successfully ‘cross the chasm’ to

the mainstream market [92]. The lack of time and sufficient accumulated resources to develop the required capabilities negates the first-mover advantage. According to this reality, pioneers are seldom ready to beat the incumbents [11,13,93]. However, in spite of this, evidence shows that pioneers sometimes win battles and dislodge incumbents [8,40,73]. This leads to our research question: Is the result of the battle random, or are there factors that determine it?

Based on all the evidence we have observed, we believe that there are several factors that determine the result: The mode of attack of the SET, the incumbents' perception, and their reaction time and committed investment volume.

The starting point is that, when an SET is introduced, incumbents might perceive it either as a threat or as an opportunity [94]. The underlying argument would be that incumbents perceive discontinuous technologies as threats of losses (a reduction in the revenues due to some customers of the dominant technology adopting the discontinuous one), while the same companies perceive potentially disruptive technologies as opportunities for gains (an increase in the revenues due to gaining new clients in underserved segments). Taking into account Kahneman and Tversky's studies [95], when people lose something, their sadness is greater than the joy they experience when they gain it. Therefore, people pay more attention to what they can lose than to what they can gain [96]. This behavior is related to the endowment effect [97], which refers to the greater suffering experienced by people when they lose something they already possess, as opposed to the pleasure felt when they receive or win that thing. That is to say, people value more what they already possess than what they do not yet possess. Accordingly, incumbents consider an SET a threat when it attempts to steal their current consumers and, therefore, harm their profits. On the contrary, if the SET does not directly attack their current market share, they will see it as an opportunity to obtain additional income. Therefore, the perception of threat or opportunity is directly dependent on the attack mode of the SET. When the SET attacks the mainstream market directly, incumbents perceive it as a threat because their current consumers begin to gravitate towards it, and their profits are affected. However, when the SET does not directly attack the mainstream market but has previously been commercialized in some other niche, segment, or market, the incumbents perceive it as an investment opportunity, which could increase their profits if they decide to take advantage of it.

Prospect theory predicts that individuals and organizations are more likely to engage in risky behaviors when they interpret something as a threat than when they perceive it as an opportunity [98]. Consequently, when incumbents perceive SET as a threat, they tend to react quickly, committing many resources to its development. However, if they view it as an opportunity, they may not commit enough resources to its development, postponing the action and continuing with their established routines while they wait to see how the situation evolves [99]. There is indeed some empirical evidence that indicates that a threat can also reduce the commitment of resources to emerging technology [100]. However, more studies show a clear relationship between risk-seeking behaviors under the perception of threats and the subsequent commitment of resources to emerging technologies [94,101,102].

In any case, it is evident that the attack mode (direct or indirect) of the SET will determine the strategy incumbents adopt. Given that discontinuous technologies are associated with a direct attack on the mainstream market and disruptive technologies with an indirect one, it seems reasonable to make the following deductions. When a discontinuous SET is introduced, incumbents will perceive it as a threat and experience a deep sense of vulnerability that they assume to be negative [103]. A discontinuous SET provides a better—real or potential—performance and, from the outset, attracts consumers away from the incumbents, reducing their revenues. Generally, facing a guaranteed loss (in this case, a reduction

in income) is something that companies are determined to avoid [98]. Therefore, when incumbents face a discontinuous SET, in most cases, they react immediately by searching for a variation in its design that will become the 'new' dominant design [104,105]. To defeat the pioneer, incumbents will then base their competitive leadership on improving the ease of use, quality, and reliability of the new technology while making radical innovations in the process and making investments to reduce production costs [106]. To ensure their participation in the mainstream market, incumbents will rarely add any new sense of originality to the product but will instead rely on their reputation, complementary assets, marketing, and consumer service capabilities [13]. As a result, incumbents can easily be the first to develop the new dominant design, despite not having pioneered the introduction of the SET, as their rapid response, vast resources, complementary assets, and experience in the mainstream market inform their success [13,15,93]. The introduction of Econyl in 2011 by the Italian company Aquafil, a leader in nylon yarn manufacturing, is one example of this phenomenon. Econyl is a regenerated yarn made from discarded fishing nets, used carpets, and other recycled plastics [107]. As the demand for more sustainable materials increased, Adidas and Gucci perceived this SET as a threat and quickly began incorporating this material into their product lines. Additionally, they leveraged their vast resources to optimize the production of recycled textiles and develop more durable, cost-effective variations in this material, which were applicable to a wider range of products. They also capitalized on their brand power and global distribution networks to position themselves as leaders in sustainability, emphasizing their environmental commitment through massive campaigns. Thus, although Aquafil was the pioneer, it was incumbents that dominated the sustainable textiles market by integrating and optimizing Econyl.

On the contrary, disruptive SETs do not directly attack the mainstream market, as they are initially marketed in some specific niche, segment, or market. Therefore, the incumbents do not perceive the technology as a real threat that might lose them consumers [94,104], but as an opportunity to obtain additional income. According to another of the principles of behavioral economics, the concavity of Kahneman and Tversky's [95] value function for gains, incumbents will perceive this additional gain as less relevant than its absolute value. This additional gain represents a small fraction of the company's total profits. Weber–Fechner psychophysical law considers that the minimum noticeable differences in any variable are directly proportional to its magnitude [23]. Therefore, it is expected that incumbents will not invest in the new, less profitable technology, but will continue to focus on the current dominant design, since it provides succulent benefits. Their organizational inertia would also contribute to preserving the status quo [104]. Potentially disruptive sustainable technology is typically based on new knowledge and capabilities that incumbents do not possess or cannot easily develop [108]. Thus, adopting this technology would render most of their previous organizational routines obsolete, requiring them to create new ones, which is a difficult, costly, and risky process [105]. Managers' inertia is also relevant because they have a worldview that is deeply rooted in their previous experiences [109,110]; therefore, they tend not to see opportunities outside the mainstream market. In other words, the potential disruptive sustainable technology is financially unattractive to the incumbents. They perceive its benefits to be low, its future profitability to be difficult to predict, and believe that alternative markets are often too small to cover the high upfront costs of developing any new technology. Finally, they believe that the potential disruptive sustainable technology can take a long time to achieve an acceptable market share [74].

In addition to strict economic criteria, other factors also reduce incumbents' incentives to invest in potential disruptive sustainable technologies [67,70,103]. For example, incumbents cannot neglect mainstream markets. Focusing on their investments in potential disruptive sustainable technologies, while competitors continue improving the current

dominant design, could affect their competitiveness in the mainstream market [111]. As a result, incumbents prefer to focus on the current dominant design, which continues to provide significant benefits, rather than developing and SET with an unappealing profitability outlook [8].

Incumbents also consider the technical and commercial risks involved in investment projects. Investments related to the current dominant design imply only technological risk because the market risk is almost non-existent, and the improvements will always satisfy the mainstream market. However, investment projects in potential disruptive sustainable technologies bear a small technological risk because, at their outset, the technology is easily improved, although they bear a remarkably high market risk, as the mainstream market tends to reject the early improvements, regardless of their technological advancements. Technological risk is assumed, since technology is a process of trial and error. However, projects that fail to meet the needs of the mainstream market have more profound consequences for technology managers, since their association with such projects may cause them to be fired. Business orthodoxy penalizes ignorance of consumers' needs. Therefore, managers tend to avoid these projects [112].

Moreover, incumbents believe that if something new has a future, they will be able to imitate it quickly [113]. This confidence may arise due to their propensity for 'accumulating creativity' [114] in the market in which they compete, allowing them to achieve remarkable success during industrial evolution. As a result, they do not see a significant risk in postponing the decision to invest in a potential disruptive sustainable technology. However, when it comes to developing a different and incompatible technological trajectory from the current one, experience in the development of the current dominant design is of little utility.

In summary, incumbents tend to neglect a potential disruptive sustainable technology and fail to immediately react to it. The perception of an opportunity whose sales are barely relevant disincentivizes managers from devoting economic or organizational resources to disruptive SET [94]. The incumbents reject such an opportunity because they consider the benefits of the disruptive SET to be insufficient and because of their lack of familiarity with the technology [101].

This behavior paves the way for the pioneer, who, while satisfying an initial group of consumers, accumulates experience and technological and economic resources. Most importantly, while satisfying its initial group of consumers, the pioneer also develops radical innovation in process and promotes economies of scale. When this co-specialization of the product and the process is introduced into the mainstream market, it provides at least a temporary competitive advantage. This co-specialization is faster in the low-end markets of developing countries because firms must implement an integrated product/process development approach from the outset simultaneously, rather than sequentially [115]. This greatly accelerates the development of the 'new' dominant design. Thus, when attacking the mainstream market, the pioneer has a design that has already been tested and a co-specialized process for developing the new product, which allows it to be highly efficient and competitive. In this context, when the incumbents attempt to react to a disruptive SET, it is too late. They do not possess the time, expertise, or necessary connections with suppliers and partners to achieve the technological, social, tangible, or intangible asset interconnection developed by the pioneer [27].

In short, the initial commercialization of a potential disruptive technology in a niche, segment, or market would reduce the risk of incumbents counterattacking the pioneer [116], as the incumbents would fail to detect the danger until the potential disruptive technology has evolved and entered the mainstream market—by which point, it is too late to win the battle.

An example of this comes from dairy proteins produced through pressure fermentation [117]. This emerging technology in the food industry uses genetically optimized microorganisms to ferment and produce specific proteins (such as casein or albumin) without raising animals. These proteins are identical to traditional ones in taste, texture, and properties, but are manufactured with a drastically lower environmental impact. Pioneering companies such as Perfect Day and Change Foods began marketing these alternative dairy proteins in the niche of premium vegan products. At the time, dairy giants, such as Nestlé or Danone, did not perceive this as a serious threat, since sales in this niche were limited and did not directly affect the mass market for conventional dairy products. Large companies viewed the benefits of this technology as insufficient compared to mass-market revenues. Furthermore, investing in precision fermentation meant changing established production and distribution processes, which entailed high costs and risks. It did not help that their experience in traditional dairy production was not applicable to the new technology. Meanwhile, the pioneering companies used their time in the niche to refine their processes, reduce costs, and scale production. The combination of technological advances and economies of scale allowed the pioneers to offer precision fermentation proteins at competitive prices. Once the product design and production process were optimized, the pioneering companies began targeting the mass market, offering products such as ice cream, cheese, and yogurt that are indistinguishable from traditional ones. At this point, the incumbents recognized the threat, since many consumers began migrating towards these more sustainable alternatives. However, when they tried to react, it was already too late. The incumbents lacked the technical knowledge necessary to compete quickly, had no connections with biotechnology suppliers, and lacked the production systems required for precision fermentation. Furthermore, the pioneers had already achieved economies of scale and captured a significant share of the mass market, gaining a lasting competitive advantage.

Nevertheless, we can observe some anomalous behaviors that do not follow this trend. In the emergence of some disruptive SETs, established companies recognized their disruptive potential early on and decided to invest in them, not only to mitigate the perceived threat but also to seize new growth opportunities in evolving markets. For example, in the early 2000s, General Electric identified the disruptive potential of wind energy in the energy sector. Instead of ignoring this trend, GE acquired the Enron Wind Company in 2002, positioning itself as a leader in the wind energy market and adapting to the transition toward more sustainable energy sources [118]. A similar case is that of Ørsted, a Danish company that originally focused on fossil fuels, which acknowledged the global transition toward cleaner energy sources as a threat to its business model. In response, the company undertook a radical transformation, divesting from fossil fuel assets and reinvesting in renewable energy, particularly offshore wind energy. Today, Ørsted is a global leader in offshore wind energy, significantly reducing its carbon footprint and shifting its focus toward sustainability [119]. In addition, Madjdi and Hüsiger [120] analyzed the behavior of three incumbent mobile network operators in Germany (T-Mobile, Vodafone, and E-Plus) and their reaction to the disruptive technology, wireless local area network technology (W-LAN). As expected, Vodafone and E-Plus perceived the disruptive technology as a commercial opportunity, but as this did not produce high-profit margins, they did not devote significant amounts of resources to face it. However, T-Mobile perceived the disruptive technology as a threat and invested aggressively in W-LAN.

This demonstrates that, sometimes, the perception of a threat directs the investments of incumbents toward disruptive technologies instead of reinforcing the current dominant design [105].

All the arguments presented can be summarized in the following assumptions: (1) The battle for the dominant design is an inevitable part of the adoption of new technologies [5,121]; (2) pioneers and incumbents compete in a structured way, each with different strengths and weaknesses [11,13,89,90,99,102,104,105]; (3) the first-mover advantage is not always decisive in the technological battle [11–16,93]; (4) the nature of an emerging technology determines its mode of entry into the mainstream market [4,5,8,15,22,35,41,43,45,66,69,75,121]; (5) the entry mode of an emerging technology influences how incumbents perceive it [23,24,95,98,99,103–105]; and (6) perception of the incumbents determines their reaction time and level of investment, shaping the outcome of the battle [94,95,101,102].

Based upon these assumptions, we propose the following working hypotheses:

Main Hypothesis

Prior studies have shown that discontinuous technologies exhibit a superior performance along existing competitive dimensions, forcing incumbents to react quickly and leverage their resources, complementary assets, and economies of scale to control the new design [13,15]. In contrast, disruptive technologies initially target niches, segments, or alternative markets, allowing pioneers to accumulate knowledge, refine their technologies, and gain an early-mover advantage before incumbents respond [8,94].

H1: *The nature of the SET determines the likely winner in the battle for dominant design. Discontinuous SETs favor the victory of the incumbent; disruptive SETs favor the pioneer's victory.*

Mediating Hypotheses

Discontinuous SETs introduce immediate performance advantages, making a direct challenge to the current dominant design inevitable [7,27,113]. In contrast, disruptive SETs initially underperform in mainstream market criteria and instead enter through niches or underserved segments, where they evolve before challenging the current dominant design [8,17,57].

H2: *The nature of the SET (discontinuous vs. disruptive) determines its mode of attack on the mainstream market. Discontinuous SETs attack the mainstream market directly, while disruptive SETs are previously commercialized in other markets.*

Behavioral economics suggests that firms are risk-averse and prioritize avoiding losses over seeking gains [23,24]. A direct attack threatens incumbents' core business, resulting in losses that incite an aggressive response [15]. Conversely, an indirect attack is seen as non-threatening and is perceived as an investment opportunity that could increase profits, leading to a calmer or non-existent reaction [104].

H3: *The SET's attack mode (direct vs. indirect) determines the incumbent's perception of it as either a threat or an opportunity. A direct attack leads incumbents to perceive the SET as a threat; an indirect attack causes them to perceive it as an opportunity.*

Studies show that firms facing threats accelerate decision-making and allocate more resources [99,102]. In contrast, when firms perceive an opportunity, they delay action, assess potential benefits, and avoid committing significant resources [105].

H4: *The incumbent's perception influences their reaction time and investment level. A threat perception involves a quick reaction and a heavy investment; a perception of opportunity implies a slow reaction and little to no investment.*

Incumbents who invest early and aggressively in emerging technology are more likely to secure dominant positions [13]. If incumbents react too late, pioneers gain a first-mover advantage, making it difficult for incumbents to recover lost ground [45,62].

H5: *The reaction time and the investment volume determine who wins the battle with regard to establishing the new dominant design. A fast reaction and heavy investment favor the incumbent; a slow reaction and low investment favor the pioneer.*

Figure 1 presents the conceptual framework that illustrates all the proposed relationships. On the one hand, it shows the direct link between the SET nature and the battle outcome (H1). On the other hand, it highlights the mediating links that explain this direct relationship: The link between the type of SET and the mode of attack (H2), between the mode of attack and the perception of the incumbent (H3), between the perception of the incumbent and their reaction time and level of investment (H4) and, finally, between the reaction time and level of investment with the final result of the battle (H5).

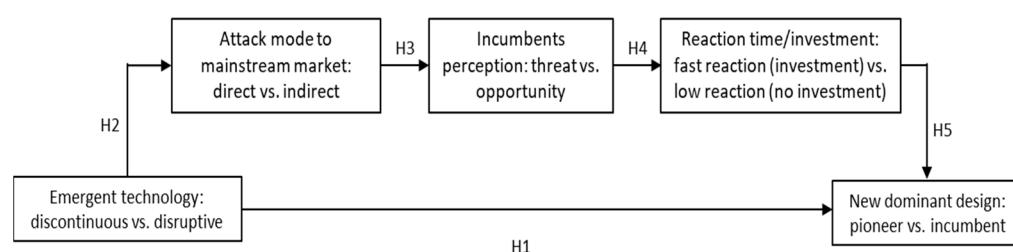


Figure 1. Research model.

While they are not refuted, these hypotheses facilitate the development of a model that explains the lack of unanimous evidence regarding the battles to establish the dominant design. By adding behavioral factors to the analysis concerning traditional contextual-only models and positioning the behavior of incumbents as a central variable, the proposed model explains why there are two opposing streams of evidence on the results of technological battles and justifies the validity of both. Likewise, generalizing this model would allow reactions and behaviors to be systematized, providing valuable lessons for pioneers and incumbents. This new integrative perspective can encourage companies to move away from their traditional behaviors and replace them with more unpredictable and anticipatory strategies that will allow them to outperform their competitors.

3. Conclusions, Implications, and Contributions

3.1. Conclusions

In this study, we enounce a set of hypotheses whose contrast would allow us to validate the following conclusions:

First, one of the main differences between discontinuous SETs and disruptive SETs is the mode of attack or entry into the mainstream market. Discontinuous SETs enter directly, while disruptive SETs use a niche, segment, or alternative market as a springboard. While previous studies on the subject (Appendix A, Sections A1 and A2) agree on the essence of what a discontinuous technology is and how it differentiates from a disruptive one, they do not relate this nature to the mode of attack on the mainstream market. Our contribution in this regard is to include the mode of entry (direct or indirect) into the mainstream market as one of the basic requirements to delimit both technologies. To do so, we define them in terms of necessary and sufficient conditions, establishing the mode of attack as the sufficient condition.

Second, the mode of attack by SETs on the mainstream market influences the perception and, therefore, the reaction of incumbents. A direct attack is perceived by incumbents as an immediate threat, leading them to react quickly and with a significant investment. However, an indirect attack is not perceived as a real threat by incumbents but rather as a potential investment opportunity that is probably unattractive. Consequently, they wait to see how the situation develops economically and strategically, and their reaction is usually delayed. While previous studies on the subject (Appendix A1, Sections A1 and A3) describe how incumbents react to different attacks using case analysis methodology, they do not explain this behavior based on the reactions implied by perceiving something as a threat or an opportunity. Our contribution in this regard is to analyze incumbents' behavior through the lens of behavioral economics, allowing us to explain and systematize their reactions based on perception.

Third, the incumbent's reaction determines who will win the battle to establish the new dominant design. If it reacts quickly enough, the incumbent is likely to win thanks to its resources, brand, and market position. However, if the incumbent does not respond quickly enough, the pioneer is more likely to prevail, as it will have time to accumulate experience, improve its efficiency, and establish a competitive advantage before the incumbent reacts. In this case, previous studies (Appendix A1, Section A3) either always point to the incumbent as the winner or always to the pioneer, supported in both cases by empirical evidence. Our contribution in this regard is to explain that this "in principle" inconsistency is not such and that the coexistence of these contrary results is justified by the different context in which each one occurs. While previous studies analyze a specific context in each case with a single possible outcome, our work allows us to simultaneously analyze all possible contexts and predict the winner in each one.

Based on the above, the final conclusion of our work, and one of the main contributions to previous literature, is that the nature of the SET is the determining factor in the outcome of the battle to make it the dominant design. Discontinuous SETs favor incumbents as winners, while disruptive SETs favor pioneers.

However, there are also some analyses of cases in which reactions and behaviors do not follow this systematic pattern. Sometimes, established companies perceive a potentially disruptive technology as a threat and react immediately, as in the case of General Electric or Ørsted with wind energy. Other times, despite not perceiving it as a threat, they invest immediately, even if the opportunity is not very attractive, as in the case of T-Mobile with W-LAN technology. These anomalies make it necessary to continue trying to refute our model or seek complementary explanations to resolve them. For example, we believe that the size and, above all, the profits of incumbents could be control variables that would allow our model to remain valid.

3.2. Contributions

Academically, this study contributes to the literature on technological strategy and dominant design by addressing persistent gaps and proposing new forms of analysis. First, it introduces a conceptual framework that allows for differentiating and analyzing SETs in terms of discontinuity and disruption. This proposal not only mitigates the existing conceptual ambiguity and lack of predictive power in this regard [37–39,46,122] but also provides a useful tool to develop consistent measurement scales for empirical validation, which will allow for theoretical advancement based on homogeneous foundations. The advance compared to previous studies is the systematization of the distinction and measurement of two variables as relevant as discontinuity and disruption. Second, the study integrates the principles of behavioral economics into the analysis of technological battles, allowing perception and behavioral responses to be included as determining variables in

the analysis. This original integration represents a significant theoretical contribution by incorporating psychological and cognitive factors into a field traditionally dominated by rationalist and structural approaches.

From a business perspective, by combining technological strategy with behavioral principles, this study offers original strategic insights for both pioneers and policymakers. On the one hand, the framework introduced allows pioneers to identify and eliminate biases that can limit their strategic vision, leading them to adopt more effective habits in their exploration of technological opportunities and to preserve their leadership by developing proactive investment strategies. On the other hand, the article helps to raise awareness among pioneers that first-mover advantage does not guarantee success if it is not accompanied by operational efficiencies, strategic alliances, and adequate management of the technology adoption curve. Finally, the study contributes to the public policy debate by demonstrating that the creation of incentives and regulatory frameworks tailored to corporate behavior can accelerate the introduction of sustainable technologies. All of this allows for the articulation of a proposal that innovatively links theory, business strategy, and sustainability.

3.3. Practical Applications

Based on our analysis, we can draw the following valuable lessons for innovation managers:

First, and based on our main hypothesis, if they wish to preserve their leadership, incumbents should never resist technologies that meet consumer needs outside the mainstream market, as it occurs with potentially disruptive SETs, regardless of their attractiveness. Innovation managers must pay attention not only to sustainable technologies that suddenly break into their markets but also to any other sustainable technologies marketed in niches, low- and high-end segments, or developing country markets. Incumbents must identify and consider pioneers in these alternative markets as potential competitors that could render current technological investments obsolete. Only by continuously monitoring different markets will they be able to predict or identify future technological disruptions before they enter the mainstream market and before it is too late to react. Investing immediately in identified sustainable technologies will allow incumbents to leverage their advantageous position in the mainstream market relative to pioneers and develop, before them, the variant of the emerging technology that will become the new dominant design. This rapid reaction will also prevent pioneers from evolving toward radical process innovation and being the first to achieve the product-process co-specialization.

Second, innovation managers must avoid concentrating all their investments on improving the 'current' dominant design. Once satisfactory performance for the consumer has been achieved in the winning criterion of the current dominant design (primary dimension), continuing to invest in it will only lead to performance oversupply, for which customers are unwilling to pay. Therefore, companies must also focus on anticipating those technological needs in which the current dominant design has not yet achieved satisfactory performance (secondary dimensions), and consumers might soon begin to prioritize. That is, incumbents should not wait for pioneers to identify the order-qualifying criteria that have the potential to become the new order-winning criterion. Instead, they should anticipate changing the current performance base and be the ones who generate the disruption. This fits with our expanded definition of disruptive technology, which implies that disruption is a dynamic activity that incumbents (not just first movers) can foster to maintain a sustainable competitive advantage when the market stagnates or when competition is intense.

Both lessons imply that companies must explore sustainable technological innovations from the demand side; that is, from the perspective of real consumer needs. If they want

to maintain their competitive advantage, it is crucial that they not only satisfy current consumer needs but also be able to anticipate those sustainable needs that will become the new criteria for winning orders in the future. Only then will they be prepared to compete when current winning criteria reach their limits or when the business environment changes.

3.4. Directions for Future Research

First, it would be interesting to investigate the different organizational designs that incumbents can implement when adopting SETs. The alternatives can be very varied: Expanding the current structure with greater investment in R&D and specialized personnel, establishing an autonomous and independent unit, developing platforms and strategic alliances, investing in pioneering startups, etc. Although some studies on this subject already exist [8,45,100], they focus on only one type of technology. However, it would be very interesting to determine the organizational design that allows for addressing both disruptive and discontinuous technologies. It should be kept in mind that these technologies can alternate or coexist in the real world throughout the evolution of the sector. In this sense, it would also be interesting to analyze the correlation that may exist between a discontinuous technology and core competencies, by enhancing market competitiveness, and between disruptive technologies and dynamic capabilities, by destroying the foundations of competition.

Another line of research, this time related to pioneers, would be to determine whether the skills and strategies required by a discontinuous pioneer are the same as those required by a potential disruptive pioneer.

A third line of research would be to introduce firm size into the model. According to the value function of prospect theory, individuals evaluate alternatives as a value function in relation to changes in profits [23]. Thus, the reaction to a threat or an opportunity can be highly heterogeneous depending on the size and, therefore, the volume of profits of the firm. In the case of a large firm with high profits, a large additional profit represents little relative value and does not attract attention. If the firm has low profits, a large additional profit represents high relative value, attracting more attention. As a result, small firms will perceive more intensely than large ones the threat posed by SETs when they appear. Furthermore, small firms are more flexible and tend to compete in niches or segments, where potentially disruptive SETs are usually introduced. By directly stealing their customers, small firms will immediately perceive these SETs as a threat. These assumptions about the relationship between firm size and reactions require additional investigation.

On the other hand, it would also be interesting to investigate the business model required for SETs to be commercialized. Can the company maintain its current business model, or should it implement a new one? Does this depend on the nature of the SETs? The answers can determine the success or failure of commercializing the new sustainable technology, so research is necessary.

3.5. Limitations

Despite its contributions, this study has some limitations. It is a theoretical study and, although corroborated by a significant number of cases, it needs more empirical research, especially since some anomalies can be observed with regard to expected behaviors. Furthermore, external factors such as government policies and environmental regulations are not included in the analysis framework and may be crucial in the battle for the dominant design in sustainable emerging technology. Furthermore, we address the definition of disruption from a restrictive perspective: Sustainable product innovation. It must be extended to sustainable process innovations and innovations in business models.

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Data Availability Statement: No new data were created or analyzed in this study.

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

Appendix A

Table A1. Theoretical and empirical studies reviewed.

Paper	Section A1. Sistematic Reviews	
	Disruptive Technology	Contribution
Cubero et al. (2021) [20]	Cubero et al. (2021) [20] review how disruptive innovations are commercialized and propose a three-phase framework: value proposition validation, business model creation, and mainstream market sales. It identifies key factors like market orientation, learning, and user involvement. The study emphasizes early commercialization efforts and aims to bridge academic research with entrepreneurial practice.	
Martínez-Vergara and Valls-Pasola (2021) [21]	Martínez-Vergara and Valls-Pasola (2021) [21] critically review how the term “disruptive innovation” has been used in academic literature. It identifies widespread conceptual confusion and proposes a clearer framework based on innovation type, market impact, and performance trajectory. The authors distinguish disruptive innovation from radical and incremental types. Their revised definition aims to guide both researchers and practitioners. The work contributes to building a more consistent theoretical foundation for future studies.	
Petzold et al. (2019) [18]	Petzold et al. (2019) [18] present a process-based view of disruptive innovation, emphasizing the dynamic unfolding of events and actions over time. Unlike traditional linear models, it highlights how disruptive innovation emerges through the synchronization of technologies, business models, and market opportunities. The study identifies three phases: Initiation, niche market entry, and mainstream disruption. Success depends on timing, strategic adaptability, and managing stakeholder perceptions. A process model is proposed to guide a better understanding and management of disruptive innovation trajectories.	
Si and Chen (2020) [19]	Si and Chen (2020) [19] examine the development and impact of disruptive innovation from a strategic management perspective. They trace the evolution of the concept and identify how new entrants disrupt markets dominated by incumbents. The authors distinguish between low-end and new-market disruptions. They emphasize the importance of business model innovation in enabling disruptive strategies. Finally, the study suggests ways incumbents can respond to or adopt disruptive innovations.	
Yu and Hang (2010) [17]	Yu and Hang (2010) [17] offer a comprehensive review of Disruptive Innovation Theory, clarifying key concepts and addressing common misunderstandings. They evaluate the predictive power of the theory and summarize research on how to enable disruptive innovation from internal, external, marketing, and technological perspectives. The authors highlight numerous inhibitors and enablers for successful implementation. They propose future research directions, including collaboration with start-ups, understanding emerging markets, and refining technological strategies. The review aims to organize fragmented literature and guide both scholars and managers.	
Antonio, J.L. and Kanbach, D.K. (2023) [22]	Antonio and Kanbach (2023) [22] conduct a systematic review to identify the key contextual factors influencing disruptive innovation. They propose a framework categorizing these factors into technological, market, organizational, and institutional dimensions. Their study highlights how external and internal conditions shape the emergence and success of disruptive innovations.	

Table A1. Cont.

Section A1. Sistematic Reviews	
Disruptive Technology	
Paper	Contribution
Dominant Design	
Fernández, E. and Valle, S. (2019) [5]	Fernández and Valle (2019) [5] propose a decision-making model to establish the dominant design. Their model considers technological, market, and strategic factors that influence which design becomes dominant.
Van de Kaa et al. (2011) [4]	Through a literature review, Van de Kaa et al. (2011) [4] identify 29 factors that influence dominant design and present a framework to address the likelihood of a format achieving dominance.
Section A2. Additional Articles on Disruptive vs. Discontinuous Technology	
Paper	Contribution
Bessant, J. (2008) [36]	Bessant (2008) [36] examines how European firms handle discontinuous innovation, which involves radical technological shifts disrupting existing markets. The study highlights challenges such as organizational inertia and resistance to change, proposing strategies for firms to adapt and thrive. The author emphasizes the need for proactive learning, experimentation, and collaboration to manage disruptive transitions effectively.
Bockmühl, S., König, A., Enders, A., Hungenberg, H. and Puck, J. (2011) [100]	Bockmühl et al. (2011) [100] investigate how incumbents respond to technological discontinuities, focusing on the intensity, timeliness, and success of their reactions. Their empirical study finds that faster and more aggressive responses increase the likelihood of maintaining a competitive edge.
Gobble, M. (2016) [46]	Gobble (2016) [46] explores the concept of disruptive innovation, clarifying its definition and distinguishing it from other forms of innovation. The article examines how disruptive innovations start in niche markets before eventually reshaping entire industries. The study emphasizes the importance of recognizing true disruption to make informed innovation and investment decisions.
Kilkkii, K., Mäntylä, M., Karhu, K., Hämmäinen, H. and Ailisto, H. (2018) [76]	Kilkkii et al. (2018) [76] propose a disruption framework to better understand the dynamics of technological and market disruptions. Their model categorizes disruptions based on changes in value creation, market structure, and business models. The study highlights how firms can anticipate and respond to disruptions by recognizing key signals and adapting their strategies.
König, A., Graf-Vlachy, L and Schöberl, M. (2021) [102]	König et al. (2021) [102] replicate and extend Gilbert's (2005) [94] study on how firms perceive and respond to discontinuous change. They examine the role of opportunity and threat perception in shaping organizational inertia and strategic adaptation. Their findings confirm that firms reacting to change as a threat often struggle with inertia, while those seeing it as an opportunity are more adaptive.
Lepore, J. (2014) [39]	Lepore (2014) [39] critiques the widespread adoption of disruptive innovation theory, arguing that it is often misused to justify risky business decisions. She challenges Clayton Christensen's framework, suggesting that historical examples of disruption are selectively interpreted.
Linton, J.D. (2002) [33]	Linton (2002) [33] explores methods for forecasting the diffusion of disruptive and discontinuous innovations in the market. The study highlights the limitations of traditional diffusion models and proposes alternative approaches to better predict adoption patterns.
Montoya, J.S. and Kita, T. (2018) [49]	Montoya and Kita (2018) [49] analyze how exponential growth in product performance impacts the theory of disruptive innovation. They argue that rapid technological advancements can accelerate market shifts, challenging traditional disruption models. Their findings highlight the need to refine disruption theory to account for exponential technological progress.

Table A1. Cont.

Section A2. Additional Articles on Disruptive vs. Discontinuous Technology	
Paper	Contribution
Muller, E. (2020) [65]	Muller (2020) [65] examines the concept of disruption by comparing Uber and Airbnb, arguing that Uber aligns more closely with disruptive innovation theory. The study refines the criteria for identifying true disruptive innovations.
Park, C. (2018) [71]	Park (2018) [71] explores how incumbents can act as disruptors by leveraging disruptive strategies in the high-performance and low-cost CPU and foundry markets. The author examines cases where incumbents drive disruption through aggressive innovation, cost reduction, and business model shifts. The study challenges the traditional view that disruption mainly comes from new entrants, showing how incumbents can reshape industries.
Ritala, P., Huotari, P. and Kryzhanivska, K. (2022) [45]	Ritala et al. (2022) [45] analyze how S&P 500 firms communicate about disruption and integrate it into their strategies. The study examines the language, framing, and strategic positioning of disruption in corporate reports and public statements. It finds that firms use disruption talk both as a defensive measure and as a way to signal innovation leadership.
Section A3. Additional Articles on Dominant Design	
Paper	Contribution
Brem, A. and Nylund, P. (2022) [110]	Brem and Nylund (2021) [110] conceptualize ‘standard inertia’—factors impeding the emergence of new standards—and examine how dominant designs can embed subsets of underlying designs, potentially affecting entire technology ecosystems.
Chen, P., Williams, C. and Agarwal, R. (2012) [90]	In this study, Chen et al. (2012) [90] explore the challenges firms face as they transition from new entrants to incumbents. They highlight how pre-entry experiences influence a firm’s ability to adapt and succeed in evolving markets, particularly when confronted with disruptive innovations.
Ferràs-Hernández, X., Nylund, P. A. and Brem, A. (2023) [87]	Ferràs-Hernández et al. (2023) [87] explore the emergence of dominant designs in artificial intelligence (AI) and how industry standards evolve in this rapidly changing field. The study examines the competition between different AI technologies, highlighting factors that influence the establishment of a dominant design, such as technological performance, market adoption, and regulatory forces.
Khanagha, S., Ramezanzadeh, M.T., Mihalache, O.R. and Volberda, H.W. (2018) [66]	Khanagha et al. (2018) [66] examine how firms respond to technological disruption in heterogeneous market environments, where uncertainty and complexity are high. They introduce the concept of “embracing bewilderment” which highlights how organizations can leverage ambiguity as a strategic advantage rather than a barrier. The study finds that successful firms adopt adaptive learning, experimentation, and flexible decision-making to navigate disruption.
Nylund, P. A., Brem, A., and Agarwal, N. (2022) [1]	Nylund et al. (2022) [1] explore how enabling technologies contribute to mitigating climate change by shaping dominant designs in environmental innovation ecosystems. The study highlights that technological standardization and industry-wide adoption are crucial for scaling sustainable innovations. It examines factors that drive the emergence of dominant designs, such as policy support, market demand, and collaborative innovation efforts.
Suarez, F.F. and Utterback, J.M. (1995) [86]	Suarez and Utterback (1995) [86] analyze how the emergence of a dominant design in an industry influences firm survival, benefiting those that adopt it while marginalizing others. Their study highlights that market entry timing and adaptability are key factors for long-term competitiveness.

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