Article

Knowledge-Based Dynamic Capabilities for Sustainable Innovation: The Case of the Green Plastic Project

Nelson Beuter Júnior * , Kadigia Faccin, Bibiana Volkmer Martins and Alsones Balestrin

Department of Economics and Business, Universidade do Vale do Rio dos Sinos (UNISINOS),
Av. Dr. Nilo Peçanha, 1600, Porto Alegre, 91330-002 Rio Grande do Sul, Brazil; kadigia@gmail.com (K.F.);
bibivolkmer@hotmail.com (B.V.M.); abalestrin@unisinos.br (A.B.)

* Correspondence: nelsonbeuterj@yahoo.com.br

Received: 23 March 2019; Accepted: 12 April 2019; Published: 23 April 2019

Abstract: A large number of recent studies show that sustainable innovation requires specific and new dynamic capabilities related to a new form of collaboration with suppliers, customers, research institutes and other related partners. These sources and external knowledges and competences require new skills in managing relationships and knowledge integration. Considering this gap, the purpose of this paper is to identify how knowledge-based dynamic capabilities (KBDCs) influence the process of developing sustainable innovations. To meet this objective, we use a procedural approach from the reconstruction of the green plastic project, in its R&D trajectory, from retrospective interviews and secondary data. Our results point to a set of practices (microfoundations) essential in the development process of sustainable innovations. We also identify the changes experienced in the knowledge capabilities of the company throughout the development of the project; this component provides the originality of this paper.

Keywords: knowledge-based dynamic capabilities; sustainable innovation; green plastic; knowledge creation; collaboration; open innovation; microfoundations; practices

1. Introduction

A large set of recent studies has been devoted to the study of sustainable innovations [1–10]. Many of these studies, such as the study by Chakrabarty and Wang [11] argue that strong innovation capabilities are associated with sustainability practices in large companies. Also, Seebode et al. [12] highlight that managing innovation for sustainability companies needs specific strategies and capabilities. Petruzzelli [13] highlighted that green innovations are characterized by high levels of intra and inter levels of complexity. This is especially true because the combination of external and internal knowledge sources (necessary in sustainable innovations) requires new skills and capabilities to integrate knowledge [14]. The capabilities to manage knowledge in collaborative relationships are fundamental for innovation [15–18].

Knowledge-based dynamic capabilities (KBDCs) are a specific type of dynamic capability (DC), which is defined as the ability to acquire, generate, and combine knowledge resources to detect, exploit, and deal with the dynamics of the environment for innovation generation [19]. KBDC studies are recent and quite promising [20]. The research developed on this theme commonly uses the quantitative approach, focusing on assessing the relationship between KBDC and performance in innovation [19,21–26]. Qualitative empirical studies of KBDC are still scarce [27,28]. In addition, as Faccin et al. [29] point out, although a series of books, articles and scientific events call attention to the importance of open and collaborative innovation for the leverage and maintenance of competitive

advantages, studies do not demonstrate that companies need to be endowed with a set of capabilities when a technological partnership begins to achieve success in the creation of knowledge and, thus, to generate innovation, especially sustainable innovation. At this point, it is important to ask: how do KBDCs influence the process of developing sustainable innovations? To answer this question and provide original contributions for the literature on sustainable innovation we use a procedural approach from the reconstruction of the development history of green plastic [30,31]. Green plastic has a unique and revealing history capable of providing important information for academic and business communities. The collaborative development project for “Green Plastic”, the first polymer produced from a renewable source of raw materials on the planet, has created a new value chain for the petrochemical industry that allows plastic to be competitive in a sustainability context [5]. To collect the data from this case, we used secondary data and a set of confirmatory interviews that allowed us to identify a set of microfoundations (practices), related to KBDC, capable of accelerating the process of developing sustainable innovations. The identified micro-foundations were classified according to Zheng et al [15], distributed in a timeline and evidenced in a visual map, as Langley [30] proposes for the analysis of data in studies with a procedural approach.

In the next sections we discuss the literature, presenting a review about KBDC and sustainable innovation management gaps. After that, we present the details about data collection and analysis and lastly, discuss results and discussions.

2. Theoretical Conversation

2.1. Knowledge-Based Dynamic Capabilities

Since a Resource Based View emerged in the 50's, many theoretical chains emphasized the importance of knowledge and its creation practices with fundamental elements for the survival of an organization and as an explanatory factor of differentials in business performance [32,33]. Thus, knowledge management is considered a strategy to increase business performance [34–36].

Knowledge can be classified in two ways: explicit and tacit [37]. An organization creates and uses knowledge converting tacit knowledge to explicit knowledge, and vice versa. Therefore, knowledge is created using a type of dialectical logic called the SECI Process (Socialization, Externalization, Combination and Internalization) [38].

For Teece, Pisano and Shuen [39], the organization's capacity to renew its tangible and intangible assets is a relevant factor for competitiveness. Thus, they developed the concept of dynamic capabilities (DC), which, in general, is the organization's ability to “[...] integrate, build and reconfigure internal and external competencies in response to rapid environmental changes” [39] (p. 516).

Among the existing forms of DCs are knowledge-based dynamic capabilities (KBDCs). KBDC refers to the “ability to acquire, generate and combine internal and external knowledge resources to sense, explore and address environment dynamics” [19] (p. 1037).

KBDC assumes the combination of two distinct fields, the dynamic capabilities view, which is focused on renewing resources to modify operational routines, and knowledge creation that focuses on generating solutions to create, transfer and use tacit knowledge. The convergence between them lies in the recognition that it is possible to generate new thoughts and capacities in the companies through practices of knowledge creation, especially in network environments [40].

Several KBDC typologies are described in the literature [20]; however the proposal by Zheng et al. [19] is a widely accepted proposition. Aligning with the proposals of Eisenhardt and Martin [41], although dynamic capabilities have some things in common among different companies, they are idiosyncratic. Therefore, even if every company is able to develop a KBDC, its level and form can be quite different and lead to different organizational performance.

Zheng et al. [19] divides KBDC into three dimensions: (a) knowledge acquisition capabilities (KAC), (b) knowledge generation capabilities (KGC), and (c) knowledge combination capabilities (KCC). The KAC is the company's ability to identify and acquire useful external knowledge; in

other words, KAC is the absorptive capacity. Absorptive capacity is the practice of recognizing the importance, assimilation and application of new knowledge for commercial purposes to increase the company's capacity to innovate [42]. Moreover, it is a DC that pertains "to knowledge creation and utilization that enhances a firm's ability to gain and sustain a competitive advantage [43] (p. 185).

The second dimension (KGC), is "a firm's ability to develop and refine the activities and processes that facilitate creating/generating new knowledge". KGC encompasses the process developed by Nonaka et al. [44], entitled SECI (Socialization, Externalization, Combination and Internalization) and the creation of knowledge through external enterprises [45].

Finally, the last component is KBDC, which is understood as the company's ability to integrate and applicate internal and external knowledge, enabling the generation of new knowledge. KBDC has the characteristic of being able to be applied inside and outside the company, such as in collaborative projects. These three dimensions work in an integrated way and tend to be cumulative [19]. Although the three dimensions of Zheng et al. [19] contribute to the understanding of KBDC, it is its operationalization in an organizational context that becomes a difficulty.

Additionally, the number of empirical papers published on KBDC is scarce. Searching the Web of Science and Scopus databases using the term "knowledge-based dynamic capabilities", only 10 such papers have been published since 2011. Denford [20]; the only paper of a theoretical nature conducted an extensive theoretical review of the KBDC field from a Resource Based View and Knowledge-Based View. Zheng et al [19], in a quantitative study with Chinese companies, investigated the mechanisms that work in innovation performance in network environments. McAdam, Reid and Shevlin [28] investigated the determinants of innovation in small and medium-sized enterprises (SMEs) at two levels: the firm and the SME network. Chen et al [24] focused their analysis on joint ventures.

In another perspective/level of the analysis, Han and Chen [26] observed the performance in innovation of Chinese industrial clusters, from the capacity of knowledge sharing of companies. Lee and Chen [25] focused on KBDC's knowledge absorption in software development in China. Monferrer, Blesa and Ripolles [21] evaluated KBDC in Spanish born globals. The leverage of the power of learning capacities in manufacturing operations was studied by Huang et al. [27], KBDC was the theoretical lens used by Han and Li [22] to observe the influence of intellectual capital on innovation performance in Chinese companies. Cheng, Yang, and Sheu [23] evaluated the influence of KBDC and open innovation in the development of radical innovations in firms from Taiwan. That said, the next topic is about sustainable innovation and its approach to KBDC.

2.2. KBDC and Sustainable Innovation

As the era of industrial societies starts to give way to the era of knowledge societies, a new historical paradigm is being born, in which countries today live the challenge of development in a much more uncertain economic environment defined by fierce market competition. In the search for excellence, speed of action, and the ability to overcome challenges, it becomes a basic requirement to transform the knowledge produced into innovation [46].

In the face of significant long-term challenges, such as climate change, population aging, desertification, water scarcity, pollution and scarcity of raw materials [47], a specific type of innovation stands out: sustainable innovation. Behnam and Cagliano [48] demonstrate that sustainability and innovation has a virtuous relationship, with a positive performance impact on each other. Thus, sustainability ceases to be a matter of marginal management and becomes an essential feature of corporate strategies and innovation [7,49,50]. The identification of the firm's dynamic capabilities described by Teece [51] and its micro-foundations for the development of sustainable innovations has been the subject of recent studies [8–10]. However, understanding how it evolves over time and identifying the transition enablers of this process are still under-explored.

The evolution of business models places sustainable innovation at the heart of organizations' strategic agendas [2,4]. This type of innovation is open, collaborative, dynamic and uncertain, extending far beyond the limits of individual firms [6,52]. Thus, collaboration is a key element in this context [1]

and emerges as a process that also depends on cooperation strategies designed to create knowledge with other partners, not just as an internal process of the company [53].

The creation of knowledge as part of the innovation process of companies, and the focus on the management of knowledge flows, becomes paramount in the face of the accelerated evolution of science and technology, which can no longer be explored in its entirety, even by large companies [53]. The search for external knowledge in collaborative relationships was called open innovation by Chesbrough [54], and the orchestration of these internal and external resources was attributed by Teece [51] to a result of the specific DC of organizations. The innovation process could, therefore, become more agile with the opening of the company to knowledge and technology relevant to this process [54]. Faccin et al. [29] point out that the great challenge of open innovation studies has been to understand “the complex process of knowledge creation, which optimizes the use of the most different types of tacit and explicit knowledge of different organizations and results in innovation” (p. 4).

Sustainability transcends firm boundaries [6,52], and open innovation requires collaborative relationships with actors outside the firm to be established [54]. Therefore, the promotion of strategies for sustainable innovation are established from both concepts [55–58].

In this sense, the use of the dimensions of Zheng et al. [19] to understand the influence of KBDC along the development of sustainable innovations is a proposal of operationalization of the construct in an organizational context. Based on the understanding that innovation can be defined by the combination of knowledge that results in the implementation of new products, processes, input and product markets or organizations [59], when the sustainable adjective agglutinates, the focus of this innovation becomes avoidance or the reduction of environmental burdens for the benefit of society as a whole or for a closer community [60]. The benefit here is not just organizational.

Thus, when talking about sustainable innovation, a holistic view is needed, thinking not only about new products, processes, etc., but also about bringing together organizational and managerial changes, the ability to enter new markets, obtain new sources of resources and to jointly meet the demand for innovation [46]. In addition, radical changes are needed, rather than incremental changes, in production and consumption systems [6]. Chen [61] proposes that the sustainable innovation capability of enterprises is comprised of knowledge innovation capability, production innovation capability, and market innovation capability.

To think of this in terms of KBDC is to turn to the organization’s ability to identify and acquire useful external knowledge (absorptive capacity), its ability to develop and refine the activities and processes that facilitate the creation/generation of new knowledge and the ability to integrate and apply internal and external knowledge, with the possibility of generating new knowledge. That is, it means looking at knowledge acquisition and creation practices as preconditions that will indirectly contribute to the collaborative practices of knowledge pooling to generate sustainable innovation [19].

3. Materials and Methods

In order to meet the goal of identifying how KBDC influences the development process of a sustainable innovation, we have carried out a unique case study with a procedural approach [30], based on the presentation of a temporal map, with the aim of revealing news related to the case. The case chosen is the Braskem Green Plastic project. Created in August 2002, Braskem is now the largest producer of thermoplastic resins in the Americas, since the integration of six companies from Odebrecth Química and the Mariani Group. Braskem has 40 industrial units, distributed in four countries (Brazil, Mexico, the United States and Germany), with a production capacity of millions of tons/year of thermoplastic resins and basic petrochemicals Braskem [62], which places it among the 20 largest chemical companies of the world [63]. Currently, Braskem is the world’s leading producer of biopolymers, with a production in the order of 200 thousand tons/year.

To reconstruct the trajectory of the project that developed green plastic, an important sustainable innovation, we organized a secondary data inventory with 295 documents, divided into: Braskem’s

documents (49), Scientific Articles (16), Books (4), Patents (34) and News (from newspaper and magazine websites - 192).

From the content analysis of these documents, we were able to reconstruct the history of the green plastic project's narrative [31]. At the same time that we paid attention to the details of the contents on these documents, we used the software ATLAS.ti as support for indicating the microfoundations used by the company during project development. Once the identification of the practices (microfoundations) was completed, we returned to the narrative in order to verify if all the practices identified with software support were in the elaborated narrative. This strategy allowed a verification of data analysis.

After this stage, we identified the time periods where explanations were necessary, as well as a set of questions to conduct retrospective interviews, which allowed for the validation of the narrative we constructed, as well as the complementation of the story. We identified seven respondents in potential. These respondents were chosen because of their relevant participation in the Green Plastic Project, namely: (interviewee 1) Production Engineer (34 min); (interviewee 2) Production Coordinator (27 min); (interviewee 3) Process Coordinator (39 min); (interviewee 4) Commercial Analyst (45 min); (interviewee 5) Researcher (15 min); (interviewee 6) Pilot Plant Engineer (19 min); and (interviewee 7) Researcher (65 min).

For all seven interviewees we asked the same initial question: “tell me the history of the green project in detail, emphasizing the actions using internal and external knowledge.” A semi-structured script was developed based on the KBDC microfoundation identification framework proposed by Zheng et al. [19] and used to guide the interviews. When the respondent spontaneously cited the information that was missing in the narrative, the interview went on as an informal conversation. Sometimes it was necessary to emphasize some event and request specific information about it.

After that process, we separated the microfoundations (practices) according to each of the KBDCs pointed to in the Zheng et al [19] framework. From there, we constructed the visual map that provides representations of the process. This type of data presentation strategy allows the decomposition of events into stages [31].

The case of the Green Plastic project was divided into three methodological stages from the identification of the most important events. Thus, as pointed out by Van de Ven and Poole [64], we adopted for this study the linear sequence pattern of phases that occur over time to produce a given result. For purposes of data collection and analysis, the schedule was divided into three distinct periods: 1) called “The incorporation of Salgema into the search for production processes with renewable raw materials”; 2) “From the beginnings of Green Plastic to the launch of Green Polyethylene (Green PE) in the market” and 3) “The Innovations Green Polyethylene and Green Polypropylene (Green PP)”. In this sense, the first step, that is the phase in which there was a predominance of practices linked to the acquisition dimension, started in the year 1995, during the acquisition of Salgema, and ended in 2003. The second phase is the one in which more practices related to the combination dimension were identified. This phase began in 2003, when the need to study ways to improve polyethylene production technology was identified, and ended in 2006. Finally, the last phase was the one that presented a set of practices, now linked to the dimension of creation, or to the combination, with the practices of creation that would be supportive for those of combination. This phase began in 2006, with the filing of the company's first patent for a petrochemical molecule obtained from renewable sources and is currently ongoing.

4. Results and Discussion

4.1. Phase 1: From the Incorporation of Salgema to the Search for Production Processes with Renewable Raw Materials (1995 to 2003)

Salgema Indústrias Químicas had its share control acquired by Odebrecht Química in 1995. It is this moment, with the incorporation of Salgema and its technology of ethylene production from ethanol—that is, the acquisition of strategic assets, that begins the first phase of the Green Plastic project.

In August 2002, Salgema became Braskem, after forming a strategic alliance of Odebrecht Química with the Mariani Group, as reported by the Química website [65]. In the period from 1995 to 2002, no relevant event related to ethanol dehydration technology occurred. In August 2002, Braskem was born with 13 industrial units in Brazil. In a public commitment disclosed to the market and to the company on 16 August 2002, Braskem was strategically positioned as a company guided by two pillars, innovation and sustainable development [66].

Soon after the creation of Braskem, the possibility of reactivating the Salgema ethanol plant was placed on the agenda, in internal discussions of the company. However, in the following year (2003), the company decided to start the search for production processes that allow the use of renewable raw materials. Immediately, the proposal to revisit Salgema's ethanol production project gained strength.

Therefore, it can be seen that in 1995 Odebrecht identified the existence of a useful external knowledge. Here, absorptive capacity was evidenced in the terms of Cohen and Levinthal [42]. An opportunity for the assimilation and application of new knowledge for commercial purposes was identified; this result leads us to understand this phase as predominantly tied to the acquisition dimension [19]. Later, this knowledge would contribute to the company's innovation capacity and, consequently, its competitiveness [42,43].

Therefore, the practices related to this dimension are understood as capable of increasing the company's ability to obtain and sustain a competitive advantage in the market [43,67]. Table 1 presents the micro-foundations, examples of actions and empirical evidence of these actions.

Table 1. Micro-foundations, examples of practices and empirical evidence of phase 1. KBDC, knowledge-based dynamic capability.

KBDC	Description	Microfundaments	Microfundaments Bound to:	Empirical Evidence
Acquisition	Practices that demonstrate the company's ability to identify and acquire useful external knowledge (absorptive capacity)	Acquisition of strategic assets	Processes and Production	"[...] The technology involved to get to this product came from an old plant that belonged to Braskem. [...] Braskem, as you know, has grown from acquisitions of other petrochemical plants, and one of the plants that it bought was the plant Salgema in Alagoas. This plant made ethene from ethanol." (Interview 7)
		Strategic alliances	Companies in the same industry	"The starting point was the decision of the Odebrecht and Mariani groups to participate as buyers in the auction of COPENE (so-called ESAE assets) and integrate to this central their own assets of the petrochemical industry, to create a new company. [...] The creation of Braskem in 2002 is a milestone in the restructuring of the Brazilian petrochemical industry process. All our actions were guided by the vision of building a world-class Brazilian petrochemical company committed to the principles of creating value, continuous innovation, excellence in products and processes and customers appreciation. Our work is founded on a quality logic, competitiveness and sustainability, where environmental responsibility is an essential part of business strategy." [66]

4.2. Phase 2: From the Beginnings of Green Plastic to the Launch of Green PE in the Market (2003 to 2006)

The interest in reactivating the knowledge acquired with Salgema for the production of ethylene, however, raises another question. Part of the managers and the technical team understood that this technology, which had been inactive for almost two decades, was obsolete, as it did not offer a product with the desired purity to produce polyethylene of the desired quality. In this way, it would be necessary to study ways to improve the technology. It is precisely this event that marks the beginning of the transition to a new phase in the Green Plastic project. However, the project did not evolve significantly until 2005, when it became part of the company's innovation pipeline.

Braskem is growing at a rapid pace, and this growth focuses on basic structuring to begin the escalation of innovation and sustainable development. In 2004, the company created the Braskem

Innovation Program, with the objective of mobilizing resources for technological innovation and operational excellence. Braskem also signed the International Declaration on Cleaner Production of the United Nations (UN) and became the first Brazilian company to sign this commitment [68]. In 2005, Braskem began to use the Life Cycle Analysis (LCA) methodology of its products and became part of the recently created Corporate Sustainability Index of the São Paulo Stock Exchange.

The year 2006 is very relevant. Braskem realized, through conversations with customers, that there was a desire for a sustainable polymer other than polyethylene to be produced. The desired polymer was polypropylene (PP), whose range of value-added applications would be higher than that of polyethylene (PE). PP is widely used in the automotive sector, electronics, household appliances and packaging. PE, for its part, has a wide application in packaging, tubes, bags and plastic films. The speech of one of the interviewees reads this:

Braskem was much provoked by them. They are a very relevant customer of the company. It was very provoked by them, in the sense of having a more sustainable plastic [...] I had the opportunity to participate in some meetings with them, the great product that they wanted, was a renewable source polypropylene ... it was not so much a polyethylene [...] because the PP has many more applications (Interviewee 4).

Producing PP from a renewable source was a technology that did not exist until then, unlike PE, which could be produced starting from ethanol. In a strategic decision, the company decides to invest in the two projects, knowing that each would have different delivery timings, as one of the interviewed researchers comments:

One was strategic to position itself in the market (green ethene) because it was easier to do—Oh, we know how to do it and we have the first Green PE certificate. While the other was strategic, from the point of view of a variety of applications with high added value ... but since one had to “start from scratch”, the path was longer [...] it was necessary to invest first in basic research, to then make the jump for industrial application (Interviewee 7).

On the one hand, Braskem is advancing with the Green PE project, designing and building a pilot plant to produce Green Ethanol in Triunfo/Rio Grande do Sul. On the other hand, Braskem has initiated internal studies to identify opportunities for production of the Green PP.

Thus, at this stage, a knowledge that had been acquired in the previous phase, through the incorporation of Salgema Indústrias Químicas, began to be perfected to launch the first Green PE of the market. It is therefore possible to integrate internal and external knowledge with the possibility of generating new knowledge [19], which will happen only in the next phase. Table 2 presents the main practices of this phase, which is characterized as a combination, because the practices of this dimension are those that directly impact the mobilized KBDC. The creation practices are more structural and/or relate to the certification that will provide support for the next step to be characterized as an association of creation and combination. This factor demonstrates that, as stated by Zheng et al. [19], that acquisition and creation practices are preconditions for combination and contribute indirectly to innovation.

Table 2. Micro-foundations, examples of practices and empirical evidence of phase 2.

KBDC	Description	Microfundaments	Microfundaments Bound to:		Empirical Evidence
Combination	Practices demonstrating the company's interest in integrating and applying internal and external knowledge.	Multidisciplinary project teams		Build on existing knowledge	"So, this technology already existed, partially, let's put it that way. Within Braskem, there were people who knew and had operated this plant. Even people who initially operated the Pilot came from the Salgema [...] because they knew the Salgema process from beginning to end. Then they came to the Pilot, just to bring this knowledge." (Interview 7)
		Partnerships with customers for the production of product innovation		Companies from different markets	"Braskem was very provoked by them. They are very relevant clients to the company. It was very provoked by them, in the sense of having a more sustainable plastic." (Interview 7)
Creation	Practices that demonstrate the company's interest in developing and refining the activities and processes that facilitate the creation/generation of new knowledge	Projects Pipeline		Management	"The implementation of Braskem's Innovation Program (PIB), which stimulates the execution of projects with new technologies and applications, occurs." [62]
		Take on voluntary commitments, which impact the firm's strategy		Management	"Braskem is the first Brazilian industry to sign the UN International Declaration on Cleaner Production." [68]
		Investing in R&D laboratories		Management	"To ensure the achievement of its objectives in this area, the company offers its clients a team of more than 150 researchers and technicians based at the Braskem Technology and Innovation Center, located in Triunfo, in the state of Rio Grande do Sul. Formed by assets whose value exceeds R\$ 300 million invested over the last years, the Center started to count in 2004 with its seventh pilot plant for the development of new resins." [69]
		Analysis of the value chain		Management	"Braskem starts using the Life Cycle Assessment (LCA) methodology of its products." [62]

4.3. Phase 3: The Innovations Green Polyethylene and Green Polypropylene (2006 to date)

Braskem entered a new phase of developing its knowledge-based dynamic capabilities on October 11, 2006. This date marks a historic milestone, as it features the deposit of the company's first patent, a petrochemical molecule obtained from a renewable source. Braskem's exclusive patent, BR200604284: Integrated process of the production of "I suffer" [70], is the first of many patents associated with renewable technologies deposited by the company.

The Green Ethene pilot plant began operations in the first half of 2007, with the objective of improving the technology of the industrial unit that operated in the 1980s in Salgema. The whole process that involved the construction of this pilot unit, its start and operation, counted only on the existing human capital within the organization. Engineers and Operation Technicians, who operated the Salgema unit, as well as professionals and researchers of the company's R&D, were part of the work team of this project.

A relevant event in this period occurred on August 21, 2007, when Braskem announced to the world: "Braskem has the first certified Green Polyethylene in the world". The certification was given by an American laboratory, which tested according to international standards for the determination of renewable carbon content [71]: "From this announcement, the company has gained another status, Braskem has become global" (Interviewee 4). Together with the announcement of this innovation, the company announced the investment in an industrial unit to produce Green Ethene, with 200 thousand tons/year capacity. This movement mobilized customers interested in innovation. National and multinational companies in the automotive, food and cosmetics sectors signed a memorandum for the purchase of Green PE, 3 years before the plant started production. This interest was solidified with the presentation of the Green PE produced at the K-fair in Düsseldorf, Germany, and with the award given by the European Bioplastics association in the category of Best Innovation in Bioplastics.

Another organizational movement in 2007 was decisive for Green Plastic to gain industrial scale. In March 2007, Braskem acquired the assets of Ipiranga Petroquímica, including the part of shares in Companhia Petroquímica do Sul (Copesul), in Triunfo/RS. With this merger, Braskem became the majority shareholder in Copesul, thereby assuming its control. At the beginning of the following year, the company decided that the Green Ethane unit would be precisely in Copesul. There is recognition here of the importance, assimilation and application of a useful external knowledge, characteristic of KBDC acquisition [19].

A multidisciplinary work group is set up for the industrial unit project in early 2008, counting on professionals from several Braskem units in Brazil but mainly professionals from the newly incorporated Copesul. All the professionals were gathered in a common office, where they remained working together for about 15 months. The industrial plant project was attended by external consultants who were chosen on time to support specific points that were not the domain of the company's professionals. Thus, the work here is characterized by the ability to integrate the knowledge of different segments, teams and individuals, which is characteristic of the KBDC combination [19].

The year 2008 also had three other relevant events, which reinforced the image of the company and Green Plastic. The first of these was the partnership with a Brazilian toy manufacturer, which launched a board game whose pieces of plastic were made with Green PE, produced in the Green Ethane pilot plant. For the first time, Green Plastic came to market as a consumer good. Another relevant point was the first agreement signed with a large Japanese company, to commercialize in the Asian market. Before Green Plastics, the company had not been able to establish such a partnership. Thus, the ability to combine knowledge from different technological or market fields can be seen here [19].

Finally, the trophy delivered to the winner of the Formula 1 Brazil Grand Prix, held in November of that year [72], was produced. This trophy was also made with Green PE produced in the pilot plant and had its design done by the architect Oscar Niemeyer. In this case, the ability to create marketing knowledge is demonstrated [19].

The year 2009 began with the launching of the “cornerstone” of the industrial plant of Green Ethane in Triunfo/RS. The design of the plant evolved rapidly and its management methodology became a milestone within the organization, as detailed by one of the engineers interviewed:

This project was an unconventional project. It was one of the first projects that were called Fast Track. It's a project where you mix steps. You do not wait to complete the project detailing step to purchase equipment. You buy the critical equipment before. This made it possible to execute this project in a very admirable time (interviewee 3).

The industrial unit of Green Ethane had its construction completed and began operations on 3 September 2010. At this moment, Braskem became the world leader in the production of biopolymers.

In addition to the speed at which the design and construction of the plant were carried out, attention is drawn to the dynamics of the creation of established knowledge on the different stages of this phase of the project. In the multidisciplinary work group established for the construction of the plant, reports of engineers interviewed show that the use of explicit knowledge, derived from previously implemented projects, was fundamental for the evolution of the Project:

The big gains we had were to get technologies we already knew and put them on the project. For example, [equipment X] equals [equipment X] from [unit A]. The [equipment Y] project is similar to the projects of all petrochemicals. [...] So we were taking the petrochemical technology that was known, to build the industrial plant (interviewee 2). The Green Ethane plant was not the same as the pilot ... the pilot plant is much simpler ... In fact, that's where the know-how of the cracker staff came in. So, everything was done with technology from the house [...] (interviewee 3).

Likewise, the tacit knowledge, derived from the experience of the participants, was essential after the departure of the industrial unit:

If you ask if the plant was operating, the result is the same as the initial project. I will answer that it is not. In these 8 years of the plant, we have changed a lot of things. It was learning and remodeling, testing parameters and conditions to get the best out of the plant. [. . .] And then, we see that in these eight years of operation, we are still learning (interviewee 2). Green Ethene, for example, I would say now, after 8 years, is a technology that is getting mature. There have been many advances since the beginning, improvements that have been made and have made it much more competitive (interviewee 7).

It was not only in the process and production that knowledge was built. There was significant organizational learning in relation to the relationship with customers, especially since the moment the innovation reached the market, according to reports from a representative of the commercial area:

Braskem is a company that produces commodities. Commodities have their pricing dictated or regulated by international oil price indicators and availability of raw material. Then, how the “green” fit into it, it was a bit different. In fact, we had to learn how to “sell a specialty”, that did not exist within Braskem. [. . .] then this is something that we also had to learn over time. Our teams today work much closer to the brand owner, the retailer, who is at the end of the day buying the concept of “Green Plastic” (interviewee 4).

The tightening of ties with large customers was one of the great gains obtained after the Green Plastic innovation. For example, numerous partnerships were established to produce solutions using Green Plastic in conjunction with these customers. This is a fact that continues today. Access to these partners is mainly due to structured and transparent management, represented in quality certifications and the signing of voluntary commitments to sustainable development. The acknowledgments received by national and international entities were also contributing aspects. An image of credibility in front of the market was built and recognized:

Today we end up accessing companies that, if it were not for the Renewables portfolio, we would not access. Or at the very least, it would be much more complex for us to access. [. . .] It can be said that the first global business that Braskem had, was the Green PE (interviewee 4).

A relevant note to the market reach achieved by Green Plastic is the transcendence from the “global to the universal”. In 2016, in partnership with a US company, Green Plastic arrived at the International Space Station after a period of research to develop a technology for the 3D printing of tools to be used by astronauts. The partnership evolved, and today, besides the plastic being renewable, all the printed material is 100% recycled for use in the printer.

In parallel to the Green PE project, a multidisciplinary team was set up to work on another strategic project of the company, a value-added plastic superior to PE known as Green PP, whose main applications are in the automotive, consumer electronics and packaging industries. As evidenced by the fact that Braskem was interested in the production of a sustainable PP solution in 2006, Braskem started to mobilize for the development of strategic partnerships that would allow the creation of a technology that had not previously existed. Partnerships with public and private institutions were formalized. Research funding bodies, universities, research centers and companies specialized in technology development were involved in this project, which it perpetuated from 2008 to 2013.

In an event in March 2008, Braskem produced, in laboratory scale, the first Green PP made from 100% renewable sources in the world. In March 2012, shortly after completion of the basic engineering project, the company announced in the media that it would make the investment in an industrial unit for the production of Green Propene. However, changes in the world market scenario, mainly associated with the reduction of oil prices and the entry of new players in North America and Asia using shale gas as a raw material (much more competitive than naphtha and ethanol) reduced the competitive potential of renewable raw materials and forced a change of investment strategy. Even if the plant had not been built (at least to date), the project itself has generated numerous organizational lessons. Starting from scratch meant that before developing the technology, it was critical to develop

the science. The first collaboration partners were, in this way, Universities. With them, basic research was begun to evaluate potential production routes in 2008, according to an engineer who participated in the project:

[...] to make propene, how would I do it? From ethanol? For this, there is no technology ... zero. Can you make propene from other raw material? I can, but then I have to find out what would be the best raw material as well. [...] Braskem began investing in a research project with FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo) and UNICAMP (Universidade de Campinas). [...] It was a project of technological routes for the production of green propene. There was no idea how this was done, everything had to be done from the beginning. This was a very big project, with 10 UNICAMP professors, 30 researchers among doctoral students, master's students and scientific initiation students, so ... it was a very big team. [...] it was a route of everything you can imagine, so that it could reach the green propene from a renewable source, other than oil. And in the meantime, other alternatives were identified [...] then, there were several ideas (interviewee 7).

Alternate paths were evaluated, leaving traditional chemical routes and going to unpredictable biochemical routes. In 2009, a partnership was established with a Danish multinational, specializing in biotechnological routes. This collaboration lasted about 4 years but did not reach a route with enough productivity to evolve to an industrial scale:

When we talk about biotechnological routes, we are talking about high risk. We are talking about something that no one has ever done in life, that there is nothing similar. So, it is very difficult to achieve technological success in a short time. I'm not even talking economically, because it really is very difficult to achieve something that is competitive in the short term. This was another great project, which lasted around 3 or 4 years in development with them, in which there were many people working on the development of this project [...] besides our people, of course (interviewee 7).

Another partnership in biotechnological studies was signed in 2010, this time with the National Laboratory of Biosciences (LNBio). LNBio is part of the National Center for Research in Energy and Materials (CNPem), a private research and development institution supervised by Brazil's Ministry of Science, Technology, Innovation and Communication (MCTIC). "The partnership we are starting today with a focus on green polymers is certainly the first step towards a more audacious, mid-term goal common for all of us: developing a chemistry-based innovation platform from renewable raw materials", said the president of Braskem, at the time, in an interview published by CNPem's communications advisor [73].

After two years of investments in several partnerships, at the end of 2010, it was decided that the first industrial unit of Green Propene to be built would use a chemical route. If the science part was solved, the stage of technology had to be defined. Two methods would be possible at this time: to develop internally or to seek a partner. According to an engineer's account, the choice at that moment was to find a partner:

Well, in fact, it was not exactly about getting a partner who already has a technology ready. Because developing technology is not something that is fast. It may take me 5 to 10 years to develop a technology that is ready but not yet mature [...] and maturation is something that only comes with practice [...] so it would take a few more years to get to this stage (interviewee 7).

What happened, however, was not an acquisition of technology. There was a need for a collaborative construction:

Technology [...] has come a good many of them. [...] They brought the main steps. [...] It was not simply to take the technology "off the shelf", because there were specificities of our

raw material [...]. Therefore, it was necessary a different look [...] so much so that there were Braskem people dedicated to this project together with the partner (interviewee 7).

Even though the Green Propene innovation has not materialized on an industrial scale, on smaller scales, it has been confirmed. Proof of this are the various patents derived from established collaborations, as well as the studies developed internally by Braskem R&D. Braskem, from 2010, has established initiatives that have increased the proposed scope for the use of renewable raw materials. In a presentation to investors held earlier this year, a new strategic direction of the organization was announced: “Be the world leader in sustainable chemistry, innovating to better serve people” [74].

Partnerships with scientific development agencies, universities, governments and private research centers have been established, focusing on the scientific and technological development of renewable chemistry. The development of the Green Butadiene [75], Green Isoprene [76], Green ethylene-vinyl acetate copolymer (EVA) [77] and the Green MEG [78] are some examples.

The relationships established in these projects, as well as those engaged in the study of Green Propene, have produced various organizational lessons. Two events, in particular, portray this condition well. The first of these events was the inauguration, on 6 June 2014, of Braskem’s Biotechnology R&D Laboratory, located in Campinas/SP. This laboratory was built for the study of new molecules from renewable sources. This event alone does not materialize the “audacious goal” affirmed by the then president of Braskem in 2010, when the partnership with LNBio was signed. According to one of the interviewed engineers, this event shows that the internalization plan of the know-how acquired dates back to a partnership signed in 2008 with a university:

[...] after this step with Unicamp, there were spin-offs from this partnership. That was Braskem setting up its own Biotechnology Laboratory, where it invested a lot. Today there are 30 Braskem researchers working, looking at renewable route options for the production of renewable source chemicals. Be it ethene, propylene or any other interesting chemical (interviewee 7).

Another relevant event was the start of Braskem’s activities in Boston, United States, on April 2018, reinforcing the organization’s strategy. The speech of a manager, responsible for the area of Innovation in Renewable Technologies, describes this position well in an interview made available on the company website:

The Boston operation will complement our metabolic engineering capabilities at our Renewable Chemistry Research Center in Campinas, as well as our materials science competencies at our Research & Development centers in Triunfo (Brazil) and Pittsburgh (USA). In addition, the unit puts Braskem in a strategic ecosystem that will allow us to take advantage of important partnerships for market research and development [79].

Collaborative relationships have been the focus of Braskem’s actions. However, organizational learning, which resulted from the collaborations, has built a solid enterprise management structure for innovation. Braskem’s R&D structure has 300 professionals distributed in three R&D centers (two in Brazil and one in the United States), 23 laboratories for quality control and process optimization and seven pilot plants. Per year, around 250 projects, on average, are in the innovation pipeline. More than 900 patents are deposited in Brazil and abroad, independently and in collaboration. Because of this, a team of professionals were established, dedicated to the management of company patents.

The number of independent patents has been increasing in recent years. The area of biotechnology is the largest contributor, showing that the know-how acquired in the collaborations lead the company to a new phase in the development of innovations, which have been mostly endogenous. However, the establishment of strategic partnerships to combine knowledge remains relevant to the organizational strategy. Since the first deposit in 2006, there have been 34 patents granted for renewable technologies.

In this third phase of the history of the Green Plastic project, Braskem established itself as a creator and combinator of knowledge, both in isolation and through collaborations with agents external

to the company. The patent filed in 2006 demonstrates the ability to create knowledge, which is a precondition for the later combination of knowledge. Thus, this phase associates the dimensions of creation and combination of knowledge, since there is now the refinement and development of activities and processes for the generation/creation of new knowledge, or the integration of internal and external knowledge aiming to generate new knowledge, characteristic of KBDC combination [19]. In addition, the pilot plant, certification and presentation of the Green Plastic in Germany demonstrates the company's ability to create technological and marketing knowledge, that is, to develop and refine the activities and processes that facilitate the creation/generation of new knowledge [19].

Thus, it can be seen that several creative practices linked to managerial and marketing knowledge have marked in this period and served as a precondition for other combination practices, characterized by partnerships, to combine internal and external knowledge to generate new knowledge. Zheng et al. [19].

This phase reveals that in the process of developing sustainable innovation there were a series of practices needed to develop and refine the activities and processes that facilitate the creation/generation of new knowledge, mainly practices related to management and marketing, which contribute indirectly to innovation. Combining practices are those that demonstrate problem-solving and partnerships that have a direct influence on sustainable innovation [19].

Table 3 summarizes and exemplifies the microfoundations of each of the dimensions mobilized in phase 3. This phase is understood as a mixture of creation and combination, because the great majority of the practices that occur are of these two dimensions of KBDC. Thus, creative practices are a precondition for combining.

Figure 1 shows, in chronological order, the practices related to the respective KBDC. If we think in terms of sustainable innovation, some issues need to be taken into account if we want to think beyond the Green Plastic Project and understand these practices as capable of providing theoretical generalizations about sustainable innovation: (a) Collaboration is a key sustainable innovation [1]; (b) radical, rather than incremental, changes are required in consumption production systems [6]; (c) sustainable innovation is at the heart of organizations' strategic agendas [2,4]; and (d) there is a need for more sustainable disruptive innovations in the chemical industries [5].

That said, first, the practices described reinforce what Zheng et al. [19] discussed about acquisition and creation being preconditions for the combination and thereby contributing indirectly to innovation. Second, due to the fact that collaboration is a fundamental part of sustainable innovation, the combination practices were the ones that occurred the most and became more numerous the closer we came to disruptive innovation (Green PP). The actions that emerged as fundamental within this micro-foundation were the partnerships formed to solve joint problems, integrating knowledge from different segments, teams and individuals, and the combination of internal and external knowledge to generate new knowledge (Green PP).

The acquisition practices proved to be important at the beginning of the Project and demonstrated that for the company to invest in sustainable innovation, it must first have the capacity to acquire fundamental knowledge of processes and production. Creation practices have occurred throughout the Project, providing support for the combination practices. In other words, to develop sustainable innovation, the company needs to be able to create knowledge internally before collaborating. In this sense, the ability to create managerial and marketing knowledge was important. As sustainable innovation is at the heart of organizational strategy, management-related actions are needed to create conditions for the creation/generation of new technological knowledge. Finally, as in chemical industries, there is a need for sustainable disruptive innovations. The combination KBDC needs to be prioritized to enable new knowledge to be generated.

Table 3. Micro-foundations, examples of practices and empirical evidence of phase 3.

KBDC	Description	Microfundaments	Microfundaments Bound to:		Empirical Evidence
Acquisition	Practices that demonstrate the ability of the company to identify and acquire useful external knowledge (absorptive capacity)	Acquisition of strategic assets		Processes and Production	"It started with PE personnel here in the South [...] it was Braskem, but here it was still Copesul. [...] So, Braskem bought everything. [...] and that's how technology came about." (Interview 3)
		Multidisciplinary project teams		Processes and Production	"I was invited, plus a few Cracker people who also had specific knowledge of this production of ethylene, and the motto was precisely to try to make improvements in the production process of Green Ethene [...] it was a nucleus that worked on the project, people from various areas of Braskem who contributed to the project." (Interview 3) "I joined Braskem in 2009 as part of the Green Propene project. [...] It was a project of technological routes for the production of green propene. I had no idea how this was done [...] so I had to do everything from the beginning. This was a very big project [...]." (Interview 7)
Combination	Practices that demonstrate the company's interest in integrating and applying internal and external knowledge.	Partnerships with customers for the production of product innovation		Companies from different markets	"The partnership between Braskem and Brinquedos Estrela (a toys maker) marked the launch in 2008 of the first pilot scale commercial project of green polyethylene, a renewable raw material made from sugarcane. Innovation, creativity and professionalism from both companies are part of the history of Banco Imobiliário Sustentável (Sustainable Monopoly). Carlos Tilkian, Chief Executive Officer of Estrela, learned about the Green polyethylene (PE) project from the newspapers and believed, from the beginning, on the sustainability appeal of the product. As a Braskem customer, I immediately thought about participating in the project using green polyethylene in one of our toys. Estrela is always in search of innovations, and we wanted to test the novelty." [80]
		Strategic Partnerships with other companies		Scientific collaboration	"And we also did with Novozymes, a biotechnology company, which we also made a partnership with that started around 2009 or 2010. The goal was to make green propylene directly from sugar in a competitive way." (Interview 7)
		Technical cooperation agreements		Scientific collaboration	"Braskem signed a partnership with the National Laboratory of Biosciences (LNBio), in Campinas, in the countryside of São Paulo, to establish a laboratory to be used by the company's researchers' team. In the new facilities will be carried out researches in the area of biotechnology for the development of a plastic using chemical route that will be at the same time economically competitive and sustainable using raw materials from renewable sources." [73]
		Participation in fairs		Marketing	"The world gets to know the green plastics at K-Fair, the biggest global event in the plastic industry in Dusseldorf, Germany." [81]
		Consortia		Companies in the same industry	"Braskem joins Europe's Bio-based Industries Consortium (BIC) [...] By joining BIC, Braskem has become part of a wider network committed to bringing bio-based products to market." [82]

Table 3. Cont.

KBDC	Description	Microfundaments	Microfundaments Bound to:	Empirical Evidence
Creation	Practices that demonstrate the company's interest in developing and refining the activities and processes that facilitate the creation/generation of new knowledge	Patent filing	Technology	Patent BR200604284: Integrated process of production of "I suffer". [70]
		Sectors/teams dedicated to innovation production	Management	"There is a team here at Braskem that only works with this. [...] It does all the management of the company's patents." (Interview 7)
		Investing in R&D laboratories	Management	"[...] After this step with Unicamp, there were spin-offs from this partnership [...] that was Braskem setting up its own Biotechnology Laboratory, where it invested a lot." ((Interview 7)
		Search for quality certifications	Management	"Braskem received new International Sustainability and Carbon Certification (ISCC) Plus and Bonsucro certifications this week for its polyethylene and basic petrochemical units, both located at the Triunfo hub in Rio Grande do Sul. With these labels, which ensure sustainable measures in the manufacturing process, Braskem meets the request of customers of Green PE, material produced from ethanol and sugarcane." [83]
		Production of product innovations	Technology	"Following the strategy of strengthening renewable chemistry, Braskem launches resin produced from sugarcane. Attentive to the competitiveness and market demand, in order to reach this new solution, Braskem made adaptations in the factory located in Triunfo-RS for the production of the renewable resin. [...] the renewable source EVA (ethylene-vinyl acetate copolymer) resin, a sustainable innovation of Braskem's I'm green brand." [77]
		Marketing initiatives that seek to add value to the product and the image of the company	Marketing	"The trophies given to the best riders in the race are more than special: besides being designed by the architect Oscar Niemeyer, they are made of the so-called" green plastic, "the creation of a Brazilian company. [...] This trophy is the first international disclosure of green plastic, in addition to participation in specialized fairs." [72]
		Strategic direction of the company	Management	"In 2010, Braskem redefined its long-term vision, formalizing the incorporation of the principles of sustainable development into its strategic management. At the end of this decade, the Company wants to play the following role in Brazil and in the world: to be the world leader in sustainable chemistry, innovating to better serve people." [74]
		Incentive to start ups, aligned with the core business	Management	"Braskem Labs is a Braskem platform formed by three programs to encourage the entrepreneurial ecosystem. Since 2015, we have worked in partnership with several players to accelerate business and startups that have a positive impact on society and the environment." [84]
		Take on voluntary commitments, which impact the company's strategy	Management	"As a Member of the Brazilian Global Compact Committee, Braskem, the largest petrochemical company in the Americas and a world leader in the production of biopolymers, will be one of the main representatives of Brazilian companies and their initiatives at the Sustainable Development Summit, of the United Nations) in New York from September 25 to 27." [85]

Figure 1. Chronological order of practices related to the respective KBDC. EVA, ethylene-vinyl acetate copolymer; PP, Polypropylene.

5. Conclusions

The inclusion of sustainability at the heart of organizations' strategic agendas, and the identification of knowledge as fundamental to innovation, make knowledge-based dynamic capabilities play a key role in the development of sustainable innovations, and these innovations are fundamental in achieving and maintaining the competitiveness of organizations. In this context, attention to the collaborative practices that allow the search for external knowledge (open innovation), which are orchestrated with the internal knowledge by the KBDC, is fundamental to understanding the knowledge creation flows and innovation processes of the companies. Therefore, the objective of this work was to investigate the influence of KBDC in the process of developing sustainable innovations.

To meet the objective, we started with the model proposed by Zheng et al. [19], which divides KBDC into three dimensions: acquisition, creation and combination of knowledge. Within each dimension, we identified Microfoundations (practices) in order to observe how they behave in the development of sustainable innovations, that is, in a process analysis.

Firstly, we identified that the practices linked to each of the dimensions change over time and that the dimensions themselves are more or less mobilized depending on the phase of the project. In this way, we have been able to identify three distinct phases in the development of the Green Plastic Project.

The first phase of the Green Plastic Project (1995 to 2003) had more micro-foundations linked to management actions and approached the acquisition dimension. This shows that in the case of sustainable green plastic innovation, it was necessary, initially, to have an absorptive capacity.

The second phase of the Project (2003 to 2006) had micro-foundations linked to management actions within the creation dimension, which were characterized as structural and pertaining to certification. However, it was the use of multidisciplinary teams and partnerships with stakeholders linked to knowledge-building practices integrating different segments, groups and individuals that made it possible to integrate and apply internal and external knowledge. The fact that the company initiated studies with PP from customer demands, as well as voluntarily sought certification of environmental quality, is an expected behavior according to previous studies by Liu et al. [86]; this process demonstrates that the power relations between supplier and customer are a strong vector of promoting sustainability. Thus, the combination, which was marked by the launch of the Green PE to the market, was the dimension that stood out in this second phase. It was also possible to realize that the practices of the creation dimension served as a precondition for those of the combination; according to Zheng et al. [19], this probably happened because sustainable innovation is considered open and collaborative [6,52], that is, it depends on the combinatorial capacities of firms [87], which are directly responsible for innovation performance according to Zheng et al. [19].

The last phase was the longest (2006—present) and was characterized by a mixture of micro-foundations of acquisition, creation and combination, with emphasis on the last two. Within the creation dimension, micro-foundations linked to management, marketing and technology actions occurred and served as support for the combination dimension that was occurring. In the combining dimension, partnerships, agreements, consortiums, were linked to actions: the knowledge of different segments, technological or market fields (companies from different markets, companies from the same industry and scientific collaboration); and adapting the internal structure and the process to combine knowledge effectively (process and production). At this stage, we also noted that the micro-foundations of acquisition and creation are presented as pre-conditions for those of combination. Thus, in this case, it was the combination capacity possessed by the company, which, in the middle of creation and acquisition, directly promoted innovation according to Zheng et al. [19].

In this way, KBDC changed because each stage of developing a sustainable innovation required a set of distinct micro-foundations tied to different organizational actions. At the beginning, the microfoundations were more linked to high management processes, which resulted in the acquisition of assets and strategic alliances. The more advanced the project, the more it was necessary to integrate knowledge practices from different segments, technological or market fields, because the company does not have the breath to supply all the technological advances demanded. Following the logic

proposed by Zheng et al. [19], acquisition and creation support combination and act indirectly on innovation, while combination acts directly on innovation performance. This result fits with the proposal of Demirel and Kesidou [88], who suggest that companies should “develop capabilities in green market sensing as such capabilities allow them to address green consumption needs” (p. 1).

This work sought to contribute to the operationalization of knowledge-based dynamic capacities in an organizational context, specifically in the development of sustainable innovations, which presented itself as a field gap. Thus, in addition to the recognition that knowledge creation practices can generate new capabilities in companies [40], the results of this study demonstrate how this can occur. For managers, such operationalization is important, for example, to reveal which practices should be favored along the flow of knowledge for the generation of innovation.

For the subject of sustainable innovations, this study signals important practices within knowledge-based dynamic capacities like investing to achieve disruptive innovation, such as the Green PP, with emphasis on cooperation strategies, in order to create knowledge with other partners. This result reinforces what has been established by Dietrich et al. [53]: When one talks about innovation and, especially sustainable innovation, a single company cannot handle the creation of knowledge necessary for new technologies alone, collaborative practices with stakeholders are fundamental to account for the knowledge flows needed for innovation. This finding indicates that, as [89] point out, policy makers should be encouraged to favor collaboration to promote sustainable innovations, since public subsidies have been important in promoting and succeeding in open innovation.

As a limitation, this study used retrospective interviews, so it is necessary to take into account that the interviewees’ reports had already happened and, in some cases, at a relatively distant time of more than 15 years. However, this limitation was minimized by the use of secondary data that was cross-referenced to the interviews to check the information. Another limitation of this study was the choice not to include the economic parameters of the company in the analyzed data scope. Thus, future studies may focus on this topic to analyze the economic impact of KBDC on company performance.

Author Contributions: This paper was written by N.B.J. in collaboration with all co-authors. The research methodology were reviewed by K.F. Data processing, results and analysis was conducted by N.B.J., K.F. and B.V.M. The final drafts and major review and editing of this paper were completed by all authors. The project supervision were done by K.F. and A.B.

Funding: This research was funded by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brasil (CAPES), Finance Code 001.

Acknowledgments: We acknowledge Braskem S.A. for their support of this study.

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

References

- Swink, M. Building collaborative innovation capability. *Res. Technol. Manag.* **2006**, *49*, 37–47. [\[CrossRef\]](#)
- Boons, F.; Montalvo, C.; Quist, J.; Wagner, M. Sustainable innovation, business models and economic performance: An overview. *J. Clean. Prod.* **2013**, *45*, 1–8. [\[CrossRef\]](#)
- Boons, F.; Lüdeke-Freund, F. Business models for sustainable innovation: State-of-the-art and steps towards a research agenda. *J. Clean. Prod.* **2013**, *45*, 9–19. [\[CrossRef\]](#)
- Loorbach, D.; Wijsman, K. Business transition management: Exploring a new role for business in sustainability transitions. *J. Clean. Prod.* **2013**, *45*, 20–28. [\[CrossRef\]](#)
- Iles, A.; Martin, A.N. Expanding bioplastics production: Sustainable business innovation in the chemical industry. *J. Clean. Prod.* **2013**, *45*, 38–49. [\[CrossRef\]](#)
- Berkhout, F. Sustainable Innovation Management. In *The Oxford Handbook of Innovation Management*; Dodgson, M., Gann, D.M., Phillips, N., Eds.; Oxford University Press: Oxford, UK, 2014; pp. 290–315.
- Varadarajan, R. Innovating for sustainability: A framework for sustainable innovations and a model of sustainable innovations orientation. *J. Acad. Market. Sci.* **2017**, *45*, 14–36. [\[CrossRef\]](#)
- Mousavi, S.; Bossink, B.A. Firms’ capabilities for sustainable innovation: The case of biofuel for aviation. *J. Clean. Prod.* **2017**, *67*, 1263–1275. [\[CrossRef\]](#)

9. Mousavi, S.; Bossink, B.; van Vliet, M. Dynamic capabilities and organizational routines for managing innovation towards sustainability. *J. Clean. Prod.* **2018**, *203*, 224–239. [\[CrossRef\]](#)
10. Mousavi, S.; Bossink, B.; van Vliet, M. Microfoundations of companies' dynamic capabilities for environmentally sustainable innovation: Case study insights from high-tech innovation in science-based companies. *Bus. Strategy Environ.* **2018**, 1–22. [\[CrossRef\]](#)
11. Chakrabarty, S.; Wang, L. The long-term sustenance of sustainability practices in MNCs: A dynamic capabilities perspective of the role of R&D and internationalization. *J. Bus. Ethics* **2012**, *110*, 205–217. [\[CrossRef\]](#)
12. Seebode, D.; Jeanrenaud, S.; Bessant, J. Managing innovation for sustainability. *R D Manag.* **2012**, *42*, 195–206. [\[CrossRef\]](#)
13. Petruzzelli, A.M.; Dangelico, R.M.; Rotolo, D.; Albino, V. Organizational factors and technological features in the development of green innovations: Evidence from patent analysis. *Innovation* **2011**, *13*, 291–310. [\[CrossRef\]](#)
14. Foster, C.; Green, K. Greening the innovation process. *Bus. Strategy Environ.* **2000**, *9*, 287–303. [\[CrossRef\]](#)
15. Martín-de Castro, G. Knowledge management and innovation in knowledge-based and high-tech industrial markets: The role of openness and absorptive capacity. *Ind. Market. Manag.* **2015**, *47*, 143–146. [\[CrossRef\]](#)
16. Lakemond, N.; Bengtsson, L.; Laursen, K.; Tell, F. Match and manage: The use of knowledge matching and project management to integrate knowledge in collaborative inbound open innovation. *Ind. Corp Chang.* **2016**, *25*, 333–352. [\[CrossRef\]](#)
17. Galati, F.; Bigliardi, B. Does different NPD project's characteristics lead to the establishment of different NPD networks? A knowledge perspective. *Technol. Anal. Strateg.* **2017**, *29*, 1196–1209. [\[CrossRef\]](#)
18. Park, J.; Ramaprasad, A. Toward ontology of designer-user interaction in the design process: A knowledge management foundation. *J. Knowl. Manag.* **2018**, *22*, 201–218. [\[CrossRef\]](#)
19. Zheng, S.; Zhang, W.; Du, J. Knowledge-based dynamic capabilities and innovation in networked environments. *J. Knowl. Manag.* **2011**, *15*, 1035–1051. [\[CrossRef\]](#)
20. Denford, J.S. Building knowledge: Developing a knowledge-based dynamic capabilities typology. *J. Knowl. Manag.* **2013**, *17*, 175–194. [\[CrossRef\]](#)
21. Monferrer, D.; Blesa, A.; Ripollés, M. Born globals through knowledge-based dynamic capabilities and network market orientation. *BRQ-Bus. Res. Q.* **2015**, *18*, 18–36. [\[CrossRef\]](#)
22. Han, Y.; Li, D. Effects of intellectual capital on innovative performance: The role of knowledge-based dynamic capability. *Manag. Decis.* **2015**, *53*, 40–56. [\[CrossRef\]](#)
23. Cheng, C.C.J.; Yang, C.; Sheu, C. Effects of open innovation and knowledge-based dynamic capabilities on radical innovation: An empirical study. *J. Eng. Technol. Manag.* **2016**, *41*, 79–91. [\[CrossRef\]](#)
24. Chen, C.J.; Lin, B.W.; Lin, J.Y.; Hsiao, Y.C. In search of parents' knowledge for joint venture's innovation. *Technol. Anal. Strateg.* **2017**, *29*, 190–203. [\[CrossRef\]](#)
25. Lee, J.-C.; Chen, C.-Y. Exploring the determinants of software process improvement success: A dynamic capability view. *Inf. Dev.* **2017**, *35*, 6–20. [\[CrossRef\]](#)
26. Han, Y.; Chen, G. The relationship between knowledge sharing capability and innovation performance within industrial clusters: Evidence from China. *J. Chin. Econ. Foreign Trade Stud.* **2018**, *11*, 32–48. [\[CrossRef\]](#)
27. Huang, T.T.A.; Chen, L.; Stewart, R.A.; Panuwatwanich, K. Leveraging power of learning capability upon manufacturing operations. *Int. J. Prod. Econ.* **2013**, *145*, 233–252. [\[CrossRef\]](#)
28. McAdam, R.; Reid, R.; Shevlin, M. Determinants for innovation implementation at SME and inter SME levels within peripheral regions. *Int. J. Entrep. Behav. Res.* **2014**, *20*, 66–90. [\[CrossRef\]](#)
29. Faccin, K.; Balestrin, A.; Volkmer Martins, B.; Bitencourt, C.C. Knowledge-based dynamic capabilities: A joint R&D project in the French semiconductor industry. *J. Knowl. Manag.* **2018**. [\[CrossRef\]](#)
30. Langley, A. Strategies for theorizing from process data. *Acad. Manag. Rev.* **1999**, *24*, 691–710. [\[CrossRef\]](#)
31. Bizzi, L.; Langley, A. Studying processes in and around networks. *Ind. Market. Manag.* **2012**, *41*, 224–234. [\[CrossRef\]](#)
32. Leonard-Barton, D. *Wellsprings of Knowledge: Building and Sustaining the Sources of Innovation*; Harv Bus C: Boston, MA, USA, 1995.
33. Grant, R.M. Toward a knowledge-based theory of the firm. *Strateg. Manag. J.* **1996**, *17*, 109–122. [\[CrossRef\]](#)
34. An, X.; Deng, H.; Chao, L.; Bai, W. Knowledge management in supporting collaborative innovation community capacity building. *J. Knowl. Manag.* **2014**, *18*, 574–590. [\[CrossRef\]](#)

35. Gonzalez, M.A.A.; Toledo, O.A.C.; Rodriguez, A.R.I. The management and construction of knowledge as an innovation strategy for collaborative learning through the use and creation of learning communities and networks. *Int. J. Knowl. Manag.* **2014**, *10*, 38–49. [CrossRef]
36. Heisig, P.; Suraj, O.A.; Kianto, A.; Kemboi, C.; Perez Arrau, G.; Fathi Easa, N. Knowledge management and business performance: Global experts' views on future research needs. *J. Knowl. Manag.* **2016**, *20*, 1169–1198. [CrossRef]
37. Nonaka, I.; Takeuchi, H. *The Knowledge Creating Company*; Oxford University Press: Oxford, UK, 1995.
38. Takeuchi, H.; Nonaka, I. *Gestão do Conhecimento*; Bookman: Porto Alegre, Brazil, 2008.
39. Teece, D.J.; Pisano, G.; Shuen, A. Dynamic capabilities and strategic management. *Strateg. Manag. J.* **1997**, *18*, 509–533. [CrossRef]
40. Easterby-Smith, M.; Prieto, I.M. Dynamic Capabilities and Knowledge Management: An Integrative Role for Learning? *Br. J. Manag.* **2008**, *19*, 235–249. [CrossRef]
41. Eisenhardt, K.M.; Martin, J.A. Dynamic capabilities: What are they? *Strateg. Manag. J.* **2000**, *21*, 1105–1121. [CrossRef]
42. Cohen, W.; Levinthal, D. Absorptive Capacity: A new perspective on learning and innovation. *Adm. Sci. Q.* **1990**, *35*, 125–152. [CrossRef]
43. Zahra, S.A.; George, G. Absorptive capacity: A review, reconceptualization, and extension. *Acad. Manag. Rev.* **2002**, *27*, 185–203. [CrossRef]
44. Nonaka, I.; Toyama, R.; Konno, N. SECI, Ba and leadership: A unified model of dynamic knowledge creation. *Long Range Plan.* **2000**, *33*, 5–34. [CrossRef]
45. Wadhwa, A.; Kotha, S. Knowledge creation through external venturing: Evidence from the telecommunications equipment manufacturing industry. *Acad. Manag. Rev.* **2006**, *49*, 819–835. [CrossRef]
46. Yawson, R.M. The Ecological System of Innovation: A New Architectural Framework for a Functional Evidence-Based Platform for Science and Innovation Policy. In Proceedings of the Future of Innovation Proceedings of the XXIV ISPIM 2009 Conference, Vienna, Austria, 21–24 June 2009. [CrossRef]
47. Montalvo, C.; Tang, P.; Mollas-Gallart, J.; Vivarelli, M.; Marsilli, O.; Hoogendorn, J.; Butter, M.; Jansen, G.; Braun, A. (Eds.) *Driving Factors and Challenges for EU Industry and the Role of R&D and Innovation*; ETEPS AISBL Report to the European Commission Directorate General Joint Research Centre e IPTS; European Techno-Economic Policy Support Network: Brussels, Belgium, 2006.
48. Behnam, S.; Cagliano, R. Be Sustainable to Be Innovative: An Analysis of Their Mutual Reinforcement. *Sustainability* **2017**, *9*, 17. [CrossRef]
49. Danso, A.; Adomako, S.; Amankwah-Amoah, J.; Owusu-Agyei, S.; Konadu, R. Environmental sustainability orientation, competitive strategy and financial performance. *Bus. Strateg. Environ.* **2019**, 1–11. [CrossRef]
50. Tseng, C.-H.; Chang, K.-H.; Chen, H.-W. Strategic Orientation, Environmental Innovation Capability, and Environmental Sustainability Performance: The Case of Taiwanese Suppliers. *Sustainability* **2019**, *11*, 1127. [CrossRef]
51. Teece, D.J. Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance. *Strateg. Manag. J.* **2007**, *28*, 1319–1350. [CrossRef]
52. Brown, P.; Bocken, N.; Balkenende, R. Why Do Companies Pursue Collaborative Circular Oriented Innovation? *Sustainability* **2019**, *11*, 635. [CrossRef]
53. Dietrich, P.; Eskerod, P.; Dalcher, D.; Sandhawalia, B. The dynamics of collaboration in multipartner projects. *Proj. Manag. J.* **2010**, *41*, 59–78. [CrossRef]
54. Chesbrough, H.W. *Open Innovation: The New Imperative for Creating and Profiting from Technology*; Harvard Business School Press: Boston, MA, USA, 2003.
55. Chesbrough, H.W.; Appleyard, M.M. Open innovation and strategy. *Calif. Manag. Rev.* **2007**, *50*, 57–76. [CrossRef]
56. Lopes, C.M.; Scavarda, A.; Hofmeister, L.F.; Thomé, A.M.T.; Vaccaro, G.L.R. An analysis of the interplay between organizational sustainability, knowledge management, and open innovation. *J. Clean. Prod.* **2017**, *142*, 476–488. [CrossRef]
57. Cappa, F.; Del Sette, F.; Hayes, D.; Rosso, F. How to deliver open sustainable innovation: An integrated approach for a sustainable marketable product. *Sustainability* **2016**, *8*, 1341. [CrossRef]
58. OCDE. The Knowledge-Based Economy. Available online: <https://www.oecd.org/sti/sci-tech/1913021.pdf> (accessed on 10 August 2018).

59. Arnold, M. Fostering sustainability by linking co-creation and relationship management concepts. *J. Clean. Prod.* **2017**, *140*, 179–188. [CrossRef]
60. Delmas, M.A.; Pekovic, S. Corporate sustainable innovation and employee behavior. *J. Bus. Ethics* **2018**, *150*, 1071–1088. [CrossRef]
61. Chen, S.-H. The Influencing Factors of Enterprise Sustainable Innovation: An Empirical Study. *Sustainability* **2016**, *8*, 425. [CrossRef]
62. BRASKEM. Perfil. Available online: <https://www.braskem.com.br/perfil> (accessed on 2 January 2019).
63. Global Top 50 Chemical Companies. Available online: <https://cen.acs.org/business/finance/CENs-Global-Top-50-chemical/96/i31> (accessed on 30 December 2018).
64. Van de Ven, A.H.; Poole, M.S. Explaining development and change in organizations. *Acad. Manag. Rev.* **1995**, *20*, 510–540. [CrossRef]
65. Química. Petroquímica: Acionistas Aprovam a Criação da Braskem. Available online: <https://www.quimica.com.br/petroquimica-acionistas-aprovam-criacao-da-braskem/> (accessed on 23 December 2018).
66. BRASKEM. Compromisso Público Braskem S.A. Petroquímica Brasileira de Classe Mundial. Available online: http://www.braskem.com.br/Portal/Principal/Arquivos/Download/Upload/Compromisso%20P%C3%BAblico_61.pdf (accessed on 23 December 2018).
67. Claver, E.; Lopez, M.D.; Molina, J.F.; Tari, J. Environmental management and firm performance: A case study. *J. Environ. Manag.* **2007**, *84*, 606–619. [CrossRef]
68. Ecopress. Braskem é a Primeira Indústria Brasileira a Assinar Declaração de Produção Mais Limpa, da ONU. Available online: <http://www.ecopress.jex.com.br/eco+watch/braskem+e+a+primeira+industria+brasileira+a+assinar+declaracao+de+producao+mais+limpa+da+onu> (accessed on 23 December 2018).
69. Braskem. Relatório Anual 2004. Available online: <http://www.braskem-ri.com.br/relatorios-anuais/2005> (accessed on 23 December 2018).
70. Morschbacker, A.L.R.C. Integrated Process of Production of I Suffer. BR200604284. 16 September 2014. Available online: <https://www.patentdelivery.com/patds/order?gui=crypt&callingapp=EDOFF&key=qwhOGMDchKHc8QZMgDNgGonVC+dywuLYbZEW38EL5eDPpKOoVIJxKYpMukrcerowEHpd91qPmWw=&n=1> (accessed on 23 December 2018).
71. ASTM D6866-12. *Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis*; ASTM International: West Conshohocken, PA, USA, 2012.
72. Globoesporte.com. Com troféu ecológico, Brasil garante ‘presença’ no pódio em Interlagos. Available online: http://globoesporte.globo.com/Esportes/Noticias/Formula_1/0,,MUL841313-15011,00-COM+TROFEU+ECOLOGICO+BRASIL+GARANTE+PRESENCA+NO+PODIO+EM+INTERLAGOS.html (accessed on 23 December 2018).
73. CNPEM. LNBio e Braskem Firmam Parceria em Plástico Verde. Available online: <http://cnpem.br/lnbio-e-braskem-firmam-parceria-em-plastico-verde/> (accessed on 23 December 2018).
74. Braskem. Relatório Anual 2010. Available online: <http://www.braskem-ri.com.br/relatorios-anuais/2011> (accessed on 23 December 2018).
75. Chemicals Technology. Genomatica and Braskem Produce Single Step Butadiene through Biological Process. Available online: <https://www.chemicals-technology.com/news/newsgenomatica-and-braskem-produce-single-step-butadiene-through-biological-process-4735614/> (accessed on 23 December 2018).
76. Environmental Leader. Braskem, Amyris, Michelin Partner on Renewable Isoprene. Available online: <https://www.environmentalleader.com/2014/09/braskem-amyris-michelin-partner-on-renewable-isoprene/> (accessed on 23 December 2018).
77. Portal de Notícias. Braskem Apresenta nova Resina Renovável Produzida em Triunfo. Available online: <https://www.portaldenoticias.com.br/noticia/5340/braskem-apresenta-nova-resina-renovavel-produzida-em-triunfo.html> (accessed on 23 December 2018).
78. BRASKEM. Braskem Assina Parceria com a Haldor Topsoe para o Desenvolvimento do MEG a Partir de Matéria-Prima Renovável. Available online: <https://www.braskem.com.br/detalhe-noticia/braskem-assina-parceria-com-a-haldor-topsoe-para-o-desenvolvimento-do-meg-a-partir-de-materia-prima-renovavel> (accessed on 23 December 2018).
79. Braskem. Braskem Inicia Operações em Boston e Fortalece Estratégia de Química Renovável. Available online: <https://www.braskem.com.br/detalhe-noticia/braskem-inicia-operacoes-em-boston-e-fortalece-estrategia-de-quimica-renovavel> (accessed on 23 December 2018).

80. Braskem. Relatório Anual 2008. Available online: <http://www.braskem-ri.com.br/relatorios-anuais/2009> (accessed on 23 December 2018).
81. Braskem. Linha do Tempo: Plástico Verde. Available online: <http://plasticoverde.braskem.com.br/site.aspx/Linha-do-Tempo> (accessed on 23 December 2018).
82. Bioplastics Magazine. Braskem Joins Europe's Bio-based Industries Consortium (BIC). Available online: <https://www.bioplasticsmagazine.com/en/news/meldungen/20181107Braskem-Joins-Europe-s-Bio-based-Industries-Consortium--BIC-.php> (accessed on 23 December 2018).
83. Petronotícias. Unidades da Braskem Recebem Certificações Internacionais para Fabricação de Polietileno Verde. Available online: <https://petronoticias.com.br/archives/79279> (accessed on 23 December 2018).
84. Labs. Quem somos. Available online: <http://www.braskemlabs.com/labs/quem-somos> (accessed on 23 December 2018).
85. ABERJE. Braskem Representa Empresas Brasileiras em Cúpula da ONU. Available online: <http://www.aberje.com.br/braskem-representa-empresas-brasileiras-em-cupula-da-onu-7/> (accessed on 23 December 2018).
86. Liu, L.; Zhang, M.; Ye, W. The adoption of sustainable practices: A supplier's perspective. *J. Environ. Manag.* **2019**, *232*, 692–701. [CrossRef]
87. Kogut, B.; Zander, U. Knowledge of the firm, Combinative Capabilities, and replication of Technology. *Organ. Sci.* **1992**, *3*, 383–397. [CrossRef]
88. Demirel, P.; Kesidou, E. Sustainability-oriented capabilities for eco-innovation: Meeting the regulatory, technology, and market demands. *Bus. Strateg. Environ.* **2019**, 1–11. [CrossRef]
89. Greco, M.; Grimaldi, M.; Cricelli, L. Hitting the nail on the head: Exploring the relationship between public subsidies and open innovation efficiency. *Technol. Forecast. Soc.* **2017**, *118*, 213–225. [CrossRef]

© 2019 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).