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# CONTRIBUTION OF ECO-INNOVATIONS TO DYNAMIC CAPABILITY BUILDING: EVIDENCE FROM THE SUGAR-ENERGY SECTOR IN SÃO PAULO

**Marco Antonio Sampaio de Jesus**[1] **Edison Fernandes Polo**[2] **Leonel Cezar Rodrigues**[3]

[1] *Doctor, University of São Paulo – Postdoctoral Program in Business Administration – USP/FEA. São Paulo, São Paulo – Brazil. prof.marco.sampaio@gmail.com*
[2] *Doctor, University of São Paulo – Postdoctoral Program in Business Administration – USP/FEA. São Paulo, São Paulo – Brazil. polo@usp.br*
[3] *Doctor, University of Araraquara – UNIARA. Araraquara, São Paulo – Brazil. lcrodrigues@uniara.edu.br*

**Abstract**
**Objective:** To characterize the dynamic capabilities of four selected companies in the sugar-energy sector, which incorporate eco-innovations in their businesses.
**Methodology:** Empirical research of a qualitative nature and explanatory approach, involving the multiple case study method, with the proper triangulation of data.
**Originality:** There are few studies in the literature involving the redesign of industrial parks into eco-industrial parks that provide opportunities for the presence of eco-innovation and the development of dynamic capabilities. This phenomenon characterizes businesses that are environmentally oriented in their production processes, whether in their base technology, raw materials, energy production, organizational structure or in the institutional structure of the industrial ecosystem.
**Main results:** The cross analysis of the data and information collected indicated the presence of dynamic capabilities dedicated to the sustainability of their businesses, based on fundamentals related to energy.
**Theoretical contributions:** The approach of Tondolo and Bitencourt (2014) was used to explain the type of repercussion of eco-innovations on dynamic capabilities and on business. The influence of eco-innovations described on the competitive behavior of the companies studied shows a direct connection with dynamic capabilities, points to the existence of a logical path and allows establishing important considerations in relation to (a) the perception of eco-innovations as a strategic opportunity, (b) finding the procedural or technological change that would solve their environmental problems, (c) developing real and latent dynamic capabilities. The conclusion is the fact that the systemic solution involved the guided use of capabilities, that characterize the dynamic environment of these companies.
**Managerial contributions:** Knowing the trajectory of environmental innovations introduced in the sugar-energy segment, with the inclusion of biotechnologies developed in the country or adapted to our reality, helps to configure environments favorable to the emergence of eco-innovative solutions that meet the UN's SDG agenda. The identified dynamic capabilities span the three main product categories – sugar, ethanol, and energy – and allowed for a strategic realignment supported by a new core business: clean energy.

**Keywords:** Sustainable innovations. Eco-innovation. Dynamic capabilities. Sugar-energy industry.

## CONTRIBUIÇÃO DAS ECOINOVAÇÕES NA FORMAÇÃO DE CAPACIDADES DINÂMICAS: EVIDÊNCIAS DO SEGMENTO SUCROENERGÉTICO DE SÃO PAULO

**Resumo**
**Objetivo:** Caracterizar as capacidades dinâmicas de quatro empresas selecionadas do segmento sucroenergético, que incorporam ecoinovações em seus negócios.
**Metodologia:** Pesquisa empírica de natureza qualitativa e abordagem explicativa, envolvendo o método de estudo de caso múltiplo, com a devida triangulação dos dados.
**Originalidade:** Na literatura se observam poucos estudos envolvendo o redesenho de parques industriais para parques ecoindustriais, redesenho que oportuniza a presença da ecoinovação e o desenvolvimento de capacidades dinâmicas. Esse fenômeno caracteriza negócios ambientalmente orientados em seus processos produtivos, seja em sua tecnologia de base, nas matérias-primas, na energia de produção, na estrutura da organização e na estrutura institucional do ecossistema industrial.
**Principais resultados:** A análise cruzada dos dados e informações coletados mostrou a presença de capacidades dinâmicas voltadas para a sustentabilidade de seus negócios, com base nos fundamentos da origem energética.
**Contribuições teóricas:** Usando a abordagem de Tondolo e Bitencourt (2014), pôde-se explicar o tipo de implicação das ecoinovações sobre as capacidades dinâmicas e sobre os negócios. O cenário da influência das ecoinovações descritas sobre o comportamento competitivo das empresas estudadas mostra conexão direta com as capacidades dinâmicas, aponta para a existência de um caminho lógico e permite estabelecer importantes considerações em relação a: (a) perceber as ecoinovações como oportunidades estratégicas; (b) encontrar a modificação processual ou tecnológica que resolvesse seus problemas ambientais; (c) desenvolver capacidades dinâmicas reais e latentes. Conclui-se que a solução sistêmica envolveu o uso orientado das capacidades que caracterizam o ambiente dinâmico dessas empresas.
**Contribuições gerenciais:** Conhecer a trajetória das inovações ambientais introduzidas no segmento sucroenergético, com a inclusão de biotecnologias desenvolvidas no país ou adaptadas para a nossa realidade, auxilia na configuração de ambientes propícios para o surgimento de soluções ecoinovadoras que atendem a agenda dos ODS da ONU. As capacidades dinâmicas identificadas alcançam as três principais categorias de produtos – açúcar, etanol e energia – e permitem um realinhamento estratégico suportado por um novo core business: energia limpa.

**Palavras-Chave:** Inovações Sustentáveis. Ecoinovação. Capacidades Dinâmicas. Indústria Sucroenergética.

## CONTRIBUCIÓN DE LAS ECOINNOVACIONES EN LA CONSTRUCCIÓN DE CAPACIDADES DINÁMICAS: PRUEBAS DEL SEGMENTO AZÚCAR-ENERGÉTICO EN SÃO PAULO

**Objetivo:** Caracterizar las capacidades dinámicas de cuatro empresas seleccionadas del segmento Segmento Azúcar-energético, que incorporan ecoinnovaciones en sus negocios.
**Metodología:** La investigación es empírica de carácter cualitativo y enfoque explicativo, involucra el método de estudio de casos múltiples, con la adecuada triangulación de datos.
**Originalidad:** En la literatura existen pocos estudios que involucren el rediseño de parques industriales para eco-parques industriales que brinden oportunidades para la presencia de la eco-innovación y el desarrollo de capacidades dinámicas. Este fenómeno caracteriza a los parques industriales que se orientan ambientalmente en sus procesos productivos, ya sea en su tecnología de base, materias primas, energía de producción, estructura organizacional y la estructura institucional del ecosistema industrial.
**Principales resultados:** El análisis cruzado de los datos y la información recolectada indicó la presencia de capacidades dinámicas orientadas a la sustentabilidad de sus negocios, con base en los fundamentos de origen energético.
**Aportes teóricos:** Utilizando el enfoque de Tondolo y Bitencourt (2014) fue posible explicar el tipo de implicación de las ecoinnovaciones en las capacidades dinámicas y en los negocios. El escenario de influencia de las ecoinnovaciones descrito sobre el comportamiento competitivo de las empresas estudiadas muestra una conexión directa con las capacidades dinámicas, apunta a la existencia de un camino lógico y permite establecer consideraciones importantes en relación a: (a) percepción de las eco-innovaciones como oportunidad estratégica, (b) encontrar el cambio procedimental o tecnológico que resolvería sus problemas ambientales, (c) desarrollar capacidades dinámicas reales y latentes. Se concluyó que la solución implicó el uso guiado de las capacidades que caracterizan al entorno dinámico de estas empresas.
**Aportes gerenciales:** Conocer la trayectoria de las innovaciones ambientales introducidas en el segmento azúcar-energético, con la inclusión de biotecnologías desarrolladas en el país o adaptadas a nuestra realidad, ayuda en la configuración de ambientes favorables para el surgimiento de soluciones eco-innovadoras que cumplan con la agenda de los ODS de la ONU. Las capacidades dinámicas identificadas abarcan las tres categorías principales de productos: azúcar, etanol y energía, y permitieron una realineación estratégica respaldada por un nuevo negocio principal: la energía limpia.

**Palabras clave:** Innovaciones sostenibles. Ecoinnovación. Capacidades dinámicas. Industria azucarera.

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## Introduction

The sustainable development goals (SDGs) agenda at the 2015 United Nations General Assembly mobilized companies to intensify their efforts to reduce the use of natural resources, given that the negative externalities of their production activities reflect on their ability to compete. The path to increasing international competitiveness involves a strategy of offering environmentally friendly products. Brazil, still new to sustainable development, must overcome challenges of poor integration in its National Innovation System [Sistema Nacional de Inovação] to catch up with countries that are more advanced in terms of sustainability (Abramovay, 2010). Even so, there are recent initiatives in some Brazilian production sectors to meet the SDGs.

In 2019, construction of the country's first power plant to generate energy from biogas was announced. Located in the municipality of São José dos Pinhais in Paraná state, the plant has a 2.8 MW generating capacity, enough to supply 2,000 homes. It was built and is operated by the CS Bioenergia Company and uses raw materials collected from sewage treatment plants and organic waste produced at shopping malls, restaurants and supermarkets in the region (Época Negócios, 2019). Along similar lines, the Enel Green Power Company project already explores the renewable energy sector in Piauí state. Enel Green Power wants to build a large solar park in Northeastern Brazil to generate 1.3 GW of energy, with a projected investment of one billion reals. In total, the park involves thirteen locations, nine of which are related to a contract from an energy auction opened by the government, and four are for direct sale by the company (Portal Energia, 2019). More recently, Unipar Carbocloro S.A. and AES Tietê Energia S.A. formalized a joint venture to generate wind energy at the Tucano wind farm in Bahia. The project should generate 155 MW of energy, equivalent to an average of 78 MW of guaranteed capacity (CVM, 2020).

Brazil's sugar-energy sector has demonstrated adherence to the SDGs through its adoption of important eco-innovations, for example: the reuse of sugarcane straw and bagasse, the recovery of vinasse, the biological control of sugarcane pests, soil recovery from sugarcane farming, the production of biodegradable plastic and the reduction of water consumption.

Sustainable development concepts became popular in the business world due to the need for companies to respond to new values institutionalized in society by the popularization of the triple bottom line concept (Cavalcanti, 2012). So-called opinion makers – such as the media, specialists and environmental movements – along with regulations promoted by public policies and by national and international institutions, increase pressure on and induce companies to adopt sustainable forms of management and production (Pinsky & Kruglianskas, 2017). Innovations in this direction ceased being sporadic and became permanent, with direct implications for business models, characterizing these companies as sustainable innovators (Barbieri *et al*., 2010), which will allow them to reap the results of sustainability strategies emerging from the systematic introduction of various innovations. This includes eco-innovations.

Identifying the effects of eco-innovations provides an idea of the phenomenon, but not necessarily its concept. As a very recent phenomenon, eco-innovation seems to be more of a cause to allow gaining boast rights than, in fact, a phenomenon critical to environmental sustainability. More in-depth studies are lacking to support eventual theories or functions, which could create a virtuous space for scientific debate. One of the first observations regarding the eco-innovation concept appears in a book by Fussler and James (1996). In an earlier article, James (1997) defined eco-innovation as new products and processes that deliver value to the client and to business, significantly reducing environmental impacts.

According to the Organization for Economic Co-operation and Development (2009) the concept of eco-innovation refers to innovations arising from demands for a new context of socio-environmental challenges, explored by scientists and entrepreneurs. They have two aggregated dimensions that determine the sustainability of business at companies whose production generates scrap and residues that degrade the environment. One dimension concerns the technical solutions that aim to solve the environmental problem caused by these processes. This dimension is linked to different types of production innovation, which can be incremental, radical, modular, architectural, or disruptive. In pragmatic terms, they refer to the redirection or substitution of basic technologies or production processes by others that do not generate scrap or waste (Nguten, Stuchey & Zils, 2014) creating environmentally friendly industrial facilities or parks. The other dimension consists of the receptivity of society to the solutions that the company employs to decrease the environmental impacts of its activities. This directly results in an increase in social sympathy for the company and its product brands.

Massard, Jacquat and Zürcher (2014) studied 160 industrial parks in 27 European and neighboring countries and recognized the presence of typical industrial ecosystems. The authors attribute the expression "industrial ecology" to the flow of materials, energy and information in these parks, referring to the "design of natural ecosystems to guide the redesign of industrial systems and offers opportunities and solutions to turn industrial parks into eco-industrial parks" (p.15) with environmentally oriented production processes, whether for their base technology, raw materials, energy production, organizational structure or institutional structure. In other words, the presence of eco-innovation as a strategic business policy for eco-industrial parks is a consequence of the industrial ecology whose presence characterizes the park.

This study understands that eco-innovation is a phenomenon inherent to opportunities for changes in industrial ecology resulting in changes to products, processes or organizational structure, which result in the maximum use of resources and supplies to ensure environmental preservation and business sustainability and which requires new modes of articulation among organizational capabilities. The value of the change lies in the environmental preservation that is reflected in business sustainability and is captured in the form of superior results, such as brand consolidation, market expansion and increased profit.

Dynamic capabilities, as suggested by Teece *et al.* (1997), adapt the company to eco-innovation, model the business and induce it to adapt itself to the requirements of eco-innovation, enabling it to increase its competitive strength.

One of the Brazilian industrial segments that shows signs of operating in accordance with industrial ecology is the sugar-energy sector, which has been characterized by the procedural similarities of is component companies, the nature of the eco-innovations with agents from the ecological sphere and its operational guidelines for environmental sustainability.

A review of the literature found studies that examined environmental innovations in the sugar-energy sector with differing objectives, such as to prepare a technical report on the zero wastewater project (Ferreira *et al.*, 2018), address the main difficulties faced in terms of innovation (Silva *et al.*, 2019), describe future prospects for the sector and its main products – sugar, ethanol, electricity and biogas (Hughes *et al.*, 2020), evaluate the evolution of the productive efficiency of the production units (Da Silva & Marques, 2021) and present the segment's technological development in the northwestern region of the state of São Paulo (Piacente *et al.*, 2022).

There is, therefore, a lack of studies that contribute to an understanding of the state of the art of dynamic capabilities applied to the sugar-energy sector resulting from the use of eco-innovations. Therefore, the objective of this study is to characterize the dynamic capabilities of four companies in the state of São Paulo, selected from this sector, which have incorporated eco-innovations into their businesses.

## Climate Change, eco-innovations, and dynamic capabilities

The Brundtland commission, comprised of representatives from twenty-one countries, formulated the first global agenda on the environment, in 1985 (Marcovitch, 2006). Since then, concerns about climate change have gained international support, with the United Nations Framework Convention on Climate Change becoming the center of global efforts to stabilize greenhouse gas emissions (Marcovitch, 2006).

Dietz *et al.* (2016) estimate that 1.8% of the global economy, around US$ 2.5 trillion worth of assets, tends to be impacted by pressures to diminish gas emissions, known as carbon risk, because they still adopt business models without giving the warranted attention to environmental sustainability. The authors argue that the production costs of goods and services can be significantly increased to the point that the costs of maintaining the environment are incorporated into the prices charged by these companies. This decreases competitiveness and economic viability for some production activities.

Environmental monitoring has intensified and the report issued by the Intergovernmental Panel on Climate Change (2013) points out that anthropogenic emissions of greenhouse gases have increased and their effects are reflected in the alteration of climate patterns, and are the main cause of the rise in the average global temperature since the middle of the 20th century.

Féres, Reis and Speranza (2011), in their study to assess the impacts of climate change on the Brazilian agricultural sector, employed an econometric model to assess how climate variations influenced the profitability of agricultural activities. The authors conclude that from 2070-2099 there will be severe impacts on the profitability of Brazilian agriculture due to climate changes and estimate reductions in profitability of around 26%, with greater negative impacts in the North, Northeast and Central West regions of Brazil. This would increase the social and economic imbalance in these regions in comparison to the South and Southeast. Thus, the necessary corrective measures and adjustments require the adoption of cleaner technologies that eliminate or mitigate greenhouse gas emissions and their effects. It is necessary to stimulate innovation at companies, especially eco-innovation.

Innovation is the implementation of a new, or significantly improved product/service, process, new marketing technique, new organizational method for business models, work organization or external relations (OECD, 2018). It should be added that an innovation, in economic terms, implies the capture (return) of the value of the modification delivered to the market. In nature, innovations can be incremental (gradual improvements), radical (improvements that interrupt the dominant technology) (Dosi, 1992; Tidd, Bessant & Pavitt, 2008), disruptive (improvements to the business model) (Christensen, 2011) and structural (improvements to architecture and content) (Henderson & Clark, 1998).

New ideas or modifications in behavior, products and processes that contribute to the reduction of environmental degradation aimed at specific ecological goals are known as eco-innovations and are aligned with the European Commission's Environmental Technologies Action Plan's definition of environmental technology for the management of pollution, water use, natural, material and/or energy resources – constituting a source of competitive advantage (Rennings, 2000; Kemp & Foxon, 2007).

In Arundel and Kemp's (2009) typology, eco-innovations are divided into (a) Environmental technologies: pollution control, management and treatment of waste and effluents, cleaner procedures, environmental instrumentation and monitoring, green energy, water consumption, and control of noise and vibration; (b) Organizational innovations: organizational methods and management systems to deal with environmental problems, substitution of inputs, changes in production facilities, formal management systems and environmental auditing; (c) Innovations in products and services that benefit the environment: green building, products and services that are less natural resource intensive, environmental consultancy, analysis, testing and engineering services; (d) Changes in green systems: environmentally friendly production and consumption systems, biological agriculture and systems based on renewable energies. Other authors add that eco-innovations create opportunities for new businesses, giving them a special connection to the concept of sustainability (Carrillo-Hermosilla, Del Rio & Konnola, 2010).

Eco-innovations result from changes in processes, products, needs for natural resources or reuse of industrial residues, conducted to minimize environmental impacts (Hart, 1995; Porter & Van Der Linde, 1995). For eco-innovations to have an effect on competitive capabilities, a company must develop internal capabilities to competitively adapt itself to its operational environment, that is, it needs to develop its dynamic capabilities.

Considered a resource-based approach, the dynamic capabilities concept emphasizes a company's concern for the competitive environment and emphasizes it's ability to collectively learn to responsibly incorporate new skills. Teece *et al*. (1997, p.516) explain dynamic competencies as "the ability of the company to integrate, construct and reconfigure internal and external competencies to serve rapidly changing environments". This means that the company renews its organizational skills, adapting them to the dynamics of the competitive environment. It does not involve remodeling itself because of the complexity of the environment in which it operates, but adapting its internal capabilities, including its business model, to respond efficiently to the variations in the environment in which it operates.

The literature on dynamic capabilities reinforces the existence of three categories of factors that must be considered: (a) Management and organizational procedures, that is, the ability to efficiently integrate internal and external resources to increase competitive capabilities, the efficiency and speed of executing tasks and the reconfiguration of productive assets in response to environmental transformations, stimulating collective and interorganizational social learning processes; (b) Position, which is comprised of the specificities of the assets that establish a competitive advantage at a given moment (they can be technological, financial, reputational, structural and institutional); (c) Trajectories, which is the direction of the path the company has been following, defined by investments, technological paradigms and external relationships, which interfere with performance (Teece *et al.*, 1997; Cabral, 2010; Yang *et al.*, 2011; Teece, 2012; Kuo *et al.*, 2016).

Market dynamics are fundamental for understanding the implication of factors that determine the dynamic capabilities of a company. For example, in markets with low or moderate dynamism, the concept is expressed in detailed routines, analytics, stable procedures and predictable results. In markets with high dynamism this is less standardized, more experimental, with flexible procedures and with consequently unpredictable results (Eisenhardt & Martin, 2000).

Ambrosini and Bowman (2009, p.35) point to an advance in dynamic capabilities as the opportunity to "replicate a process or system that is operating at a respective business unit or expand the value of the resource by using it in a new domain, such as the application of a technology in a new group of businesses".

Tondolo and Bitencourt (2014, p.140) searched in the antecedents (trajectory) for processes and implications of dynamic capabilities for the business and present a typology in which processes "allow companies to explore the opportunities offered by the external environment […] involving absorptive, innovative and adaptive capabilities."

Thus, generating innovations that respect or favor the environment helps to increase the capability for continuity of businesses and the ecosystems to which they apply. (Barbieri, 1997). Barbieri's conclusions are reinforced by the results of a Princeton University (USA) study that points to a need for companies to adopt new models of productive processes and resource consumption practices, which are strategic to their business, contributing to the reduction and mitigation of greenhouse gases (Socolow *et al.*, 2004).

## Sugar-energy sector

In the second half of the 16th century, sugarcane farming expanded in Brazil, especially in the country's Northeast. In the 17th century, with its growth in Cuba and the Antilles, sugar production in Brazil expanded to the states of Pará and Amazonas, mainly for the production of cachaça. Thus, sugar, technologically modified, gained increased financial value, and created a path for the reinvention of the sugar-energy sector. In the colonial period, sugar was Brazil's main export product, and known as "Brazilian white gold", due to its importance to the Portuguese economy. In the 19th century, the states of São Paulo and Rio de Janeiro became major centers of production. The large-scale consumption of sugarcane for fuel began after the first oil crisis (1973), with the production of anhydrous alcohol. Although the rise in consumption significantly increased the income of the sugar-alcohol segment, it caused serious environmental problems (Canabrava, 2005).

Over time, and especially since the implementation of Brazil's national alcohol program known as ProÁlcool in the 1970s, the sector's production volume increased significantly, requiring frequent expansion to the land area used to cultivate sugarcane. This caused negative reactions from society and environmentalists, who began to question inefficient practices for treatment of production waste and its inadequate disposal, forcing the sector to seek more environmentally friendly technological solutions.

In 2017, due to its climate conditions and the technologies for planting, harvesting and production, Brazil became the world's largest producer and exporter of sugar, accounting for 20% of world production (≈ 35 million tons) and 40% of exports (≈ 26 million tons), followed by India, the European Union and Thailand (26, 18 and 11 million tons, respectively). The sugarcane production chain – including the segments of inputs, primary agricultural production activities, industry and transport and trade services – reached 113.27 billion reals in 2015 (approximately 1.9% of the Brazilian GDP) (CEPEA/ESALQ/USP, 2017).

More recently, macro environmental economic factors, such as the deregulation of the sector, the decrease in price competitiveness due to the fall in international oil prices and the scarcity and increased cost of credit, brought difficulties to many companies in the segment, especially those with poorly professionalized management. This context led to a restructuring and the emergence of large business conglomerates after a series of takeovers of smaller sugar and alcohol planters and producers.

A recent event promoted by the TV program Globo Rural (2021) that featured the specialists Gonçalo Pereira (professor and coordinator of the Unicamp genomics and bioenergy laboratory), Marcelo Morandi (General Director of Embrapa Meio Ambiente [Embrapa Environmental]), and Bertholdino Teixeira Junior (a member of the board of União Nacional da Bioenergia [National

Bioenergy Union]) in a discussion of the advances in the sugar-energy sector toward sustainability. One of the challenges highlighted was the need to communicate to society and investors what the sector does, helping attract investment in sustainable practices and improve the understanding of sustainable development in agribusiness.

## Methodological procedures

This study analyzes the perception of social actors, based on their experiences and decision-making responsibilities, regarding the relationship between eco-innovations and dynamic capabilities, at a limited number of selected companies in the sugar-energy sector, in the state of São Paulo. It is an empirical study in progress, of a qualitative nature and with an explanatory approach. It is qualitative in nature because the phenomenon of the dynamic capabilities of eco-innovation is examined from the perspective of the researchers; the approach is explanatory because the phenomenon is explained using the current theory of the fundamentals of dynamic capabilities.

A multi-case study method was used (Yin, 2015). According to this author, research that seeks answers to “how” and “why” is characteristically appropriate to the case study method. This is the situation of this study, since it characterizes how the dynamic capabilities of the companies studied were suitable to responding in a competitive manner to environmental requirements, given the destructive nature of the traditional processes of alcohol production.

Therefore, to generate theory from the findings of the case study, Eisenhardt’s (1989) recommendations were followed: (a) organize the construction of the study, (b) use multiple sources in the data collection and integrate them into theoretical constructs, (c) select four to ten cases, and (d) conduct intra-case analysis to add originally unforeseen aspects of the research, and inter-case analysis to find similarities, or potential management patterns among the cases studied. Eisenhardt (1989) affirms that the theoretical content of a multi-case study can be extrapolated depending on the technique used in the collection, analysis and interpretation of data. Bardin’s (2011) content analysis method was applied to the interpretation of the collected data.

The primary data obtained from interviews, observation, and document analysis of the four companies, collected between November 2018 and May 2019, was organized into two groups: Implemented Eco-Innovations – in accordance with eco-innovation and industrial ecology concepts – and Dynamic Capabilities, considering factor categories and category functions. Then they were compiled and compared by frequency (preponderance) and subjected to discursive textual content analysis in accordance with Bardin (2011). The synthesis of the analysis is presented in Table 1 - Main influences of the dynamic capabilities originating from eco-innovations.

## Social subjects of the research

With support from the consultant in sugar-energy technology of the Industrial Sugarcane Union (UNICA), ten companies from the industry were initially selected for the study, considering that they had adopted environmental innovations, had the largest product portfolio and high sugarcane milling volumes. After making contact and issuing invitations to participate in the research, only four showed interest and availability to participate in the interview and allow the use of their data: Bioserv S/A, Copersucar S/A, Grupo São Martinho S/A and Grupo USJ.

The interviewees were directly responsible for the questions that involved the environment as well as employees who worked in functions with decision-making roles regarding technologies, processes, quality, research and development and socio-environmental responsibility.

## Presentation and discussion of the results

The four companies adopted very similar field and industrial technologies for alcohol production, with some variation due to supply chains and logistics. All of those selected adopt universal compliance practices. Strategically, they also adopt a production emphasis – considering the balance between sugar and alcohol – guided by the international price of sugar: price favorability for sugar induces greater sugar production; otherwise, greater ethanol production.

Knowing the eco-innovations and the strategic decisions of the companies studied made it possible to analyze their behavior within the sugar-energy industry. The four selected are publicly traded companies and have specific objectives for respecting the environment. Their stock is traded on the Novo Mercado da Bolsa Balcão Brasil (B3) [an over-the-counter Brazilian stock market] comprised of companies that adopt policies of governance and informational transparency above and beyond those required by law. This transparency allows greater dialogue with investors and stakeholders. The sustainability reports have a specific section where activities resulting from sustainability policy are explained in accordance with Global Reporting Initiative standards.

## A brief history of the companies

### *Bioserv S/A*

Bioserv, created in 2009, is a company within the Dutch conglomerate Louis Dreyfus Company (1851). It is the world's second largest sugarcane processor, employing more than thirteen thousand people in the production of sugar, ethanol, animal feed, yeast, powdered molasses, and energy. The company participates in activities supporting sustainability, notably the Programa Prisma aimed at reducing water consumption, effluents, solid waste and atmospheric pollutants, as well as risks from chemical products.

### *Copersucar S/A*

Established in 1959, Copersucar is a cooperative of associated mills. It is Brazil's largest seller of sugar and ethanol, responsible for 6.9% and 3.7%, respectively, of all alcohol and sugar consumed worldwide. Copersucar sees its core business as being "energy", which is explicit in its sustainability policy: energy for life, energy for growth and energy for movement. In 1969 it founded the Sugarcane Technology Center [Centro de Tecnologia Canavieira], the world's largest sugarcane biotech center. It holds important international certifications including: Bonsucro, which involves sustainability standards for sugarcane producers; others from the Environmental Protection Agency and the California Air Resources Board, which allow it to sell ethanol in the United States; and an International Sustainability and Carbon Certification, which allows the sale of ethanol in Europe.

### *Grupo São Martinho S/A*

Established in 1910, the company currently has a vertical business model (from field to agro-industry) and employs more than twelve thousand people in four facilities in the states of São Paulo and Goiás. The group recently consolidated control of 100% of the Boa Vista mill, after a seven-year joint venture with Petrobrás Biocombustables. This plant has modern facilities and is dedicated exclusively to generating bioenergy. São Martinho has an installed sugarcane milling capacity of 24 million tons per year and sells electricity on the free and regulated contract markets, generating 913 GWH on the free market.

### *Grupo USJ*

The group began in 1944 and today employs around 10,500 people. Its SJC Bioenergia plant, a joint venture with Cargill, processes alcohol from a mix of corn, sorghum, and sugarcane. It sells sugar, ethanol, and electricity. The group is certified by the following quality assurance standards: FSSC 22000, food security management system; ISO 9001:2015; SMETA, which pertains to ethical commerce; Bonsucro, which involves sustainability standards for sugarcane producers; Ethanol Mais Verde [Greener Ethanol], pertaining to sustainability best practices for sugar-energy production; and that of the California Air Resources Board, for the sale of ethanol in the state of California.

### *Eco-innovations characteristic of the sugar-energy industry*

Six eco-innovations are the most characteristic elements of sugar-energy companies. The eco-innovations observed, and systematically described by the four companies as fundamental for guiding their businesses, were not developed, and incorporated simultaneously, but form part of the companies' behavior and their business profile. Many incorporated or adapted existing agents into the ecological ecosystem itself to perform the central role of eco-innovation – to solve an environmental problem – in harmony with industrial ecology as discussed by Massard, Jacquat and Zürcher (2014). The six eco-innovations are presented below.

> *Reuse of sugarcane straw and bagasse.* Straw and bagasse are production residues used in the cogeneration of thermal and electrical energy for a company's own consumption, while the surplus is sold on the market. Bagasse is also used in animal feed, as a raw material in the furniture industry, in the chemical fertilizer industry and in the production of second-generation ethanol. The implementation costs of energy cogeneration using bagasse and straw represent, on average, 50% of the costs of a hydroelectric plant. Environmentally, the cogeneration of energy is also a solution of great economic value for sugarcane residues (Ramos & Nachiluk, 2017).
>
> *Vinasse recovery.* A by-product of the fermentation of ethanol, vinasse is rich in minerals and organic material. It is deadly to rivers and groundwater, due to its consumption of oxygen in the water. When inactivated, however, it is rich in minerals and raw protein. It can be used in irrigation-based fertilization of sugarcane fields, in the place of mineral and chemical products. Thus, its use increases soil fertility due to its influence on the growth of microbial activity, acting directly on the chemical, physical and biological properties of the soil, reducing demand for water and lowering production costs (Da Silva, Griebeler & Borges, 2007).
>
> *Biological control of the sugarcane borer.* The sugarcane borer (*Diatrea sacchralis*), common in sugarcane, is the crop's main pest. In its young phase the borer feeds on leaves and in its adult phase it penetrates the softer parts of the stalk until it reaches the sugarcane core, opening galleries and causing the weakening and death of buds. This increases wind toppling and inhibits aerial growth and rooting. The biological antidotes *are* the wasp species *Trichogramma gallo* (a parasitoid of the borer eggs) and *Cotesia flavipes* (a parasitoid of larva longer than 1.5 cm). They can be raised on a large scale and do not present risks to nature or humans (Bernardes, 2003; Poletti, 2012).
>
> *Soil recovery of sugarcane plantations.* Burning prior to sugarcane harvesting increases $CO_2$ emissions and kills microfauna and flora that are needed for soil regeneration. Mechanized harvesting eliminates burning and generates a large quantity of straw. The mechanical briquetting of straw and use of the briquettes allows controlling erosion, humidity, temperature, level of organic material, nutrients and weeds, reviving the soil and increasing productivity (Hassuani & Celente, 2019).

*Biodegradable plastic production.* Through a partnership with the Instituto de Pesquisas Tecnológicas [Technological Research Institute] and the Instituto de Ciências Biomédicas da Universidade de São Paulo [Biomedical Sciences Institute of the University of São Paulo], Copersucar's Sugarcane Technology Center was able to produce polyhydroxybutyrate (PHB). This polymer decomposes in around twelve months, a great environmental leap when compared to the 100 years needed for petroleum derived polymers (plastics). In addition to the environmental benefits, the technological advances in the production of this biodegradable plastic have also delivered significant cost reductions (Toledo, 2012).

*Reduction of water consumption.* Burning prior to harvesting requires washing the cane before it is crushed to ferment the mash. With the mechanization of the harvest, the process of dry cleaning the cane was introduced, using blowers and sieving, which allows separating the straw from the cane before it enters the chopper (the mill). This process increases milling capacity and reduces the cake volume in the filter, but the main benefit is in water savings (Dunham, Bontempo & Fleck, 2011).

## Discussions

This step evaluated potentially valuable proposals based on current business capabilities, client needs and potential for business growth. Tondolo and Bitencourt's (2014) approach is used to explain the kinds of implications eco-innovations have for the dynamic capabilities and on business. The sphere of influence of the six described eco-innovations on the competitive behavior of the group of companies studied shows a direct connection with dynamic capabilities, points to the existence of a logical path and allows establishing important considerations.

The first involves perceiving eco-innovations as opportunities. The companies studied, facing a threat to their business survival if the drop in environmental sustainability were to go unchecked, perceived that the solution was not just a response to a demand, but also a business opportunity. The focus on sustainability can ensure the continuity and perpetuity of the business and maintain impressive results

Secondly, it was necessary to find the procedural or technological change that would resolve the environmental problems. Going beyond their individual research and development limits, the companies sought solutions outside their walls and found them in the context of an eco-industrial cluster: the Sugarcane Technology Center. The changes proved to gradually solve the environmental problems. Moreover, as previously mentioned, the changes needed to guarantee returns through the capture of their embedded value. This value was captured in economic expansion, in the expansion of their captive markets, mainly to countries with greater environmental requirements, and in the increase of the acceptability of their brands and image, taking advantage of the fact that eco-innovations are innovations of an ecological nature.

Thirdly, solutions via eco-innovation could only have the desired effect if the companies had latent or actual dynamic capabilities, so they could use the needed innovations to their advantage. On the other hand, they could also develop these capabilities and, as they develop, leverage their businesses and fulfill the conceptual function of dynamic capabilities (Teece *et al*., 1997). According to the people interviewed, the capabilities were, in a way, latent at the companies, as the environmental pressure was such that there would be no internal resistance to eco-innovations as long as they proved capable of solving the problems that were a priority for allowing business continuity.

The systemic solution, as a whole, involved the guided use of capabilities that characterize the dynamic environments of the companies studied, although this was not always explicit. On the one hand, the absorptive capacity allowed identifying and capturing technologies, in an open innovative process, which could be useful for solving problems. On the other hand, a company must understand a technology to incorporate it successfully. That is, companies would need innovative capabilities to be able to understand and handle technologies for their benefit, and to that end, invest in organizational learning to properly incorporate the eco-innovations.

Furthermore, the new environmental commitments, even if resolved using absorbed and incorporated technologies, require each company to have structural and competitive standards to enable the changes to be successful. Thus, their response to new competitive conditions requires them to have adaptive capability. The reinterpretation of their new mode of competition, now based on an ecological technological platform, would necessarily lead to changes in their business model. As financially successful companies for having maintained conventional and linear production, they needed to make respect for the environment a priority and reorient their business models and market positioning in line with this priority.

Table 1 presents the results – regarding the characterization of dynamic capabilities for eco-innovation within the sugar-energy industry – of the cross analysis between the cases studied and the following models obtained from the review of the literature: categories of factors, functions of the categories and necessary dynamic capabilities.

Management procedures were influenced by eco-innovation through a combination of absorptive, innovative, and adaptive capabilities, in that order of preponderance (greater influence). According to Tondolo and Bitencourt (2014), innovative capability has a greater preponderance than adaptive capability because the solutions have a technological bent and require prior knowledge of the more easily incorporated technical procedures. Currently, the presence of capabilities has a greater influence on processes that involve production than on administrative processes. In the structural reconfiguration of productive processes, innovative capability was the most predominant.

**Table 1**

*Main influences of dynamic capabilities originating from eco-innovations*

| Factor Categories | Functions of the Categories | Necessary Dynamic Capabilities [Preponderance] |
|---|---|---|
| Based on Teece *et al.* (1997), Cabral (2010), Yang *et al.* (2011), Teece (2012) and Kuo (2016) | | Based on Tondolo and Bitencourt (2014) |
| **Management and production processes** | Identify and capture solutions in the external environment. | Greater: Absorptive<br>Lesser: Innovative and Adaptive |
| | Integrate and coordinate resources for their incorporation into solutions | Greater: Absorptive and Innovative<br>Lesser: Adaptative |
| | Provide intra-organizational social and collective learning | Greater: Absorptive and Innovative<br>Lesser: Adaptative |
| | Reconfigure and transform the structure of productive processes adapted to new technologies | Greater: Innovative and Adaptive<br>Lesser: Absorptive |
| **Positioning** | Explore the degree of specificity of the company's assets (**technological**, reputational and structural) that establish a competitive advantage in its market segment | Greater: Innovative<br>Lesser: Adaptive and Absorptive |
| **Strategic Trajectories** | Redirect the company's strategic direction, with particular influence from technological paradigms that redefine competitive positioning and approaches. | Greater: Adaptive and Innovative<br>Lesser: Absorptive |

**Key:** Levels of preponderance of capabilities: **Greater** (blue circle) **Lesser** (green circle)
**Source**: Research data (2021).

Strategic positioning has significantly changed over time. The absorption of eco-innovations as a basis for a company's production processes has induced companies to make the environmental dimension a component of their business model. A new language and a new dialogue have been established with clients and communities, changing their perceptions about companies and their businesses. The foundation of strategic repositioning lies to a greater degree in innovative capability (incorporating technologies to develop ecological solutions and make them part of their repositioning) and to a lesser degree in adaptive capability.

With repositioning, the strategic trajectory of companies came to be influenced by innovative capabilities, as the basis for repositioning, and by adaptive capabilities, as a support for the continuation of changes that came to determine business models. As traditional sugar and fuel alcohol producers with environmentally abusive production processes, they needed to respond to society and the market, and they found responses at the Sugarcane Technology Center: the eco-industrial cluster with expertise in self-sustainable sugarcane technology. More recently, they have been repositioned as energy producers by a new strategic shift, exploring eco-innovations that enable the recycling of the solid waste byproducts resulting from their production activities, to generate and sell electrical and thermal energy.

## Conclusions

There is a high level of interaction with the external environment to find technological solutions in the sugar-energy industry, which required greater articulation with governments and research and development centers to achieve gains in the three branches of sustainable development: environmental, social, and economic. The sector is technically qualified, with the world's lowest alcohol and sugar production costs, has the potential to increase its production capacity, and to gain international recognition for its alignment with the premises of a low carbon economy.

The trajectory of environmental innovations introduced into the sector, with the inclusion of biotechnologies developed in, or adapted for, Brazil, has created a favorable environment for the emergence of eco-innovative solutions that meet the UN's SDG agenda. The dynamic capabilities identified extend to the three main categories of products – sugar, ethanol and energy – and allow a strategic realignment supported by a new core business: clean energy, represented by sugar as energy for life, ethanol for transportation and electricity for development. This indicates that there has been a clear repositioning of their business models and competitive strategies, supported by eco-innovations and dynamic capabilities.

Table 1 shows that the dynamic capabilities of the companies studied have led to profound changes in their administrative and production processes, their business models and strategic positioning, due to the eco-innovations adopted. In addition, in the opinion of the interviewees, this has changed the perceptions of their brands and images found in the market and among social agents, moving them from the uncomfortable position of environmentally abusive producers, to being beneficent producers of clean, useful energy.

The changes in the strategic trajectories demonstrate how much dynamic capabilities can affect a company's direction and business fundamentals. Empirical evidence for the four companies studied demonstrates that the capability to perceive, absorb, interpret, and leverage business in accord with new eco-innovative premises has altered the business focus, sources of profitability, strategic control, and nature of their competitive capacity. Dynamic capacities, latent or properly developed, have allowed companies to change their positioning and competitive strategies based on the eco-innovations incorporated. Technologies that support eco-innovation, incorporated via their dynamic capabilities, have now become key priorities in learning platforms, internal structural adaptations, and competitive strategies.

In terms of limitations, this qualitative study is restricted by the fact that its results cannot be directly generalized. However, Eisenhardt's (1989) recommendations for generating theory from case study findings were fulfilled through the structure of the study construction process, the use of multiple sources for data collection and their integration into theoretical constructs, by selecting four companies relevant to the segment, and by the intra-case and inter-case analysis, which found similarities and managerial patterns among the companies studied.

Finally, conducting studies that bring contributions from different approaches or methodologies is recommended, to improve models based on dynamic capabilities and eco-innovations, which can be generalized for the use of Brazilian agribusiness companies.

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