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WATER, ENERGY AND FOOD NEXUS:
HOW TECHNOLOGIES IMPLEMENTATION AFFECTS AGRIBUSINESS MODELS

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Ichigo, Ichie. Cada encontro, um momento.

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ABSTRACT

The concept of the Nexus between Water, Energy and Food (WEF Nexus) is presented as a way to mitigate tradeoffs and increase synergies between water and energy for food production, in order to guarantee access to quality water, energy and food. In this context, the role played by the private sector in promoting water, energy and food security is vital. The innovation of business models through the implementation of technologies is a means of incorporating the principles of the WEF Nexus into the business model. This research aims to analyze the impact of new technologies on agribusiness models, under a WEF Nexus and Sustainability perspective. Through a systematic literature review, it was possible to identify the WEF Nexus principles. Seven case studies were also carried out with technologies implemented in four agribusiness companies. Each technology was analyzed based on the principles of WEF Nexus. In addition, the impact of the implementation of these technologies on business models was analyzed, in terms of value proposition, value creation and delivery system and value capture. As contributions, this research establishes a link between WEF Nexus and business models literatures, through a practical analysis of the WEF Nexus approach, in addition to describing the changes that occured in business models during the innovation and adjustment phases of the innovation process. It also presents the concept of WEF Nexus as a way to overcome the challenges faced when companies innovate their business models towards sustainability.

Keywords: WEF Nexus; Sustainability; Sustainable Business Model Innovation; Technology Implementation.

RESUMO

O conceito do *Nexus* entre Água, Energia e Alimento (*Nexus* AEA) se apresenta como uma forma de mitigar os tradeoffs e aumentar as sinergias entre água e energia para a produção de alimentos, para garantia de acesso à água, energia e alimento de qualidade. Nesse contexto, é vital o papel desempenhado pelo setor privado para a promoção das Seguranças Hídrica, Energética e Alimentar. A inovação de modelos de negócios por meio da implementação de tecnologias é um meio de incorporar os princípios do *Nexus* AEA no modelo de negócios. Esta pesquisa tem como objetivo analisar o impacto de novas tecnologias em modelos de negócios para agricultura, sob uma perspectiva de *Nexus* AEA e Sustentabilidade. Por meio de uma revisão sistemática da literatura, foi possível identificar princípios do *Nexus* AEA. Foram realizados também sete estudos de caso com tecnologias implementadas em quatro empresas do ramo de agricultura. Cada tecnologia foi analisada a partir dos princípios do *Nexus* AEA. Além disso, foi analisado o impacto da implementação dessas tecnologias nos modelos de negócios, em termos de proposição de valor, sistema de criação e entrega de valor e captura de valor. Como contribuições, estabelece uma ligação entre as literaturas de *Nexus* AEA e modelos de negócios, por meio de uma análise prática da abordagem do conceito de *Nexus* AEA, além de descrever as mudanças que ocorrem nos modelos de negócios durante as fases de inovação e ajuste do processo de inovação. Apresenta também o conceito de *Nexus* AEA como uma forma de superar os desafios enfrentados quando empresas inovam seus modelos de negócios para a sustentabilidade.

Palavras-Chave: *Nexus* AEA, Sustentabilidade, Inovação de Modelos de Negócios Sustentáveis, Implementação de Tecnologia.

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LIST OF ABBREVIATIONS

AEA *Nexus*	Nexus Água, Energia e Alimentos
IWRM	Water Resources Management
VP	Value Proposition
WEF Nexus	Water, Energy and Food Nexus
SLR	Systematic Literature Review
SO	Specific Objectives

CONTENT

1 INTRODUCTION

The ‘State of Food Security and Nutrition in the World 2020’ Report estimates that in 2019, prior to the COVID-19 pandemic, almost 690 million people (8.9% world population) were undernourished (FAO et al., 2020). The increase of global demand and changes in climate and land have imposed the need for an effective and integrated management of natural resources as water, energy and food (BAZILIAN et al., 2011; RASUL; SHARMA, 2016; SHARMINA et al., 2016). The concept of Water, Energy and Food Nexus (WEF Nexus) Thinking is in evidence since the late 2000s (HELLEGERS et al., 2008). It was formally discussed for the first time in the Bonn2011 Conference, in 2011, as an integrated and cross sectorial approach that can increase the water, energy and food security by expanding the synergies and mitigating the trade-offs of these resources interconnections (HOFF, 2011).

The WEF Nexus Thinking can be seen as a new paradigm through which natural resources can be considered and managed (ALLOUCHE; MIDDLETON; GYAWALI, 2015; BENSON; GAIN; ROUILLARD, 2015; LECK et al., 2015; SMAJGL; WARD; PLUSCHKE, 2016). Also, WEF Nexus Thinking is presented as a way of analysis to quantify the interconnections between Nexus nodes (water, energy and food) (CHANG et al., 2016; ZHANG C. et al., 2018; ZIOGOU; ZACHARIADIS, 2017). Government, industry and society in general are responsible for managing the natural capital.

As others players in society, the private sector depends directly on natural capital. It is axiomatic the vital role of businesses throughout the entire process of extracting, producing, distributing, consuming, recycling and disposing natural resources. Previous researches in the field of WEF Nexus have indicated the need to integrate the WEF Nexus Thinking to business and society in order to promote sustainability (LEESE; MEISCH, 2015; MIDDLETON et al., 2015; VLOTMAN; BALLARD, 2014).

In the context of corporate sustainability, Sustainable Business Models are challenged to propose, create, deliver and capture a value that exceeds the financial one, in a constant sustainable value exchange with multiple stakeholders (MORIOKA et al., 2018; MORIOKA; BOLIS; CARVALHO, 2018). In this sense, the literature has stressed the significance of research on sustainable business models that can exist in harmony with the concept of WEF Nexus and green economy (GREEN et al., 2017).

Sustainable Business Models, which consider the needs of many stakeholders (including the environment), require the outlining of sustainable value flow systems (EVANS et al., 2017), and innovation is an impressive manner to introduce sustainability to the business (EVANS et al., 2017; GEISSDOERFER; VLADIMIROVA; EVANS, 2018). In this sense, Morioka, Bolis and Carvalho (2018) proposes a framework to discuss the Sustainable Value Exchange Matrix of businesses models.

According to Mohtar (2017) four levers are capable of foster a path to sustainable business models aligned with WEF Nexus: social, financial and political awareness and engineering technologies. These technologies, aligned with WEF Nexus Thinking, would allow businesses to create synergy between water, energy and food, reduce interdependences (increasing resilience), improve equity and distribution and promote water, energy and food security (MOHTAR, 2017).

However, in the private sector opportunities are missed because there is little integration between research on WEF Nexus and Sustainable Business Models (GREEN et al., 2017). Specially in the area of agribusiness, there are studies proposing mathematical assessing models and scenarios forecast. However, no studies were found about the impact of integrating WEF Nexus concerns into Business Models.

Aiming to meet this research gap, the present research seeks to answer the following research question: **How does implementation of new technologies aligned with WEF Nexus Thinking affect agribusiness business models?**

Thus, the main objective of this research is *to analyze the impact of new technologies on agribusiness business models under a WEF Nexus and Sustainability perspective.*

The specific objectives (SO) include:

#1 *to identify WEF Nexus principles;*

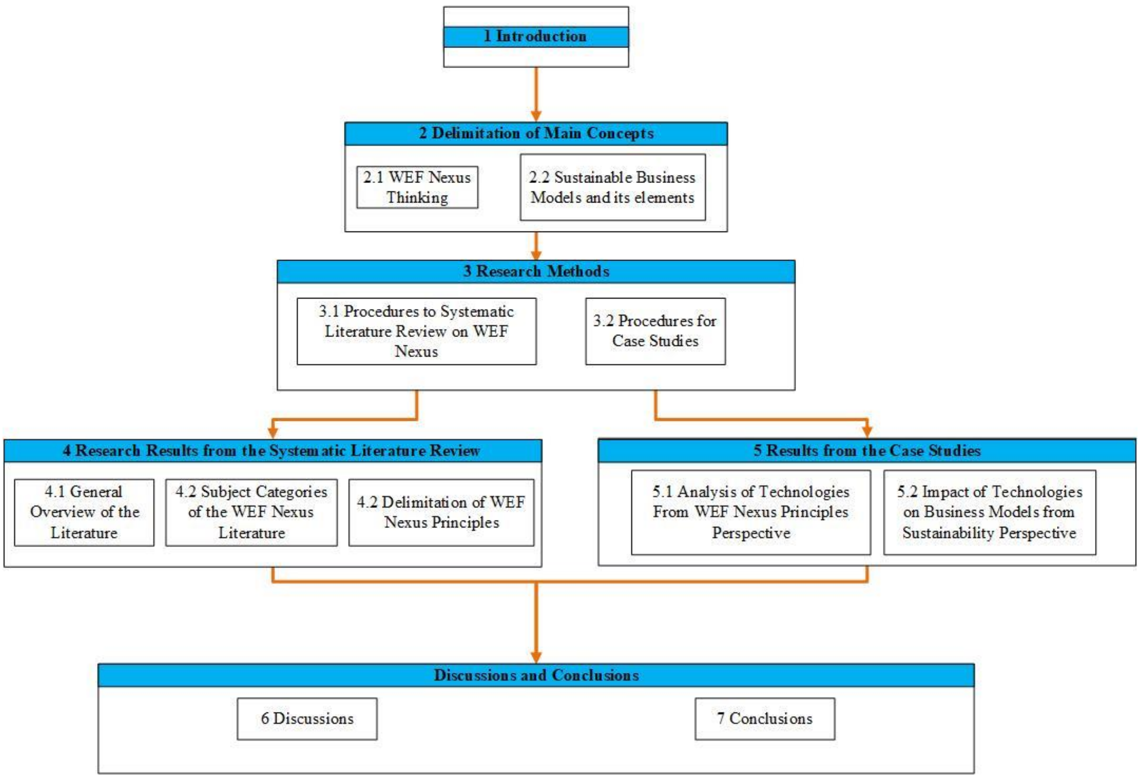
#2 *to analyze WEF Nexus principles of technologies implemented in the agribusiness;* and

#3 *to analyze how the implementation of these technologies impacts agribusiness towards more sustainable business models, in terms of value proposition, value creation and delivery system and value capture.*

The development of knowledge about technologies aligned with WEF Nexus and their impact on Business Models meets two research gaps. First, little has been explored about qualitative parameters to analyze technologies and business models from a WEF Nexus perspective. Second, understanding how technologies aligned to WEF Nexus affect business models can enable companies to better plan and maximize stakeholders' value capture from an innovation process (HEIKKILA et al., 2018; KHAN; BOHNSACK, 2020).

Fig. 1 presents this Dissertation structure. Section 2 brings a brief delimitation of WEF Nexus and Sustainable Business Models. In Section 3, the research procedures are outlined. The results from the Systematic Literature Review are presented in Section 4 RESEARCH RESULTS FROM THE SYSTEMATIC LITERATURE REVIEW4, insofar as the results from case studies are shown in Section 5. Results are discussed and Section 6. Lastly, Section 7 brings research conclusions.

Fig. 1 - Dissertation Structure



2 DELIMITATION OF MAIN CONCEPTS

In this section, the main concepts useful to the construction of this project are outlined.

2.1 WEF Nexus Thinking and Sustainability

The Bonn Conference, in 2011 (HOFF, 2011), addressed the need for water, energy and food security through the consideration of a Water-Energy-Food Nexus (WEF Nexus). This approach proposes the consideration of the interconnections between these resources in a multi-sectorial analysis, aiming to maximize the synergies and mitigate the trade-offs between them (ALBRECHT; CROOTOF; SCOTT, 2018; BAZILIAN et al., 2011; ENDO et al., 2017; HOFF, 2011; RASUL, 2014).

The WEF Nexus Thinking is an approach that considers the understanding and acknowledgment of the relationship between water, energy and food. However, the interaction of these elements is not that simple, but is rather highly complex and fuzzy (LI et al., 2019; MARTINEZ; BLANCO; CASTRO-CAMPOS, 2018). In dry seasons, the scarcity of water can signify, in addition to the decrease in water availability, a tradeoff between its allocation to food production or energy generation (PERRONE; HORNBERGER, 2016). This scenario is aggravated when considered climate changes, urbanization, population growth and abandonment of agricultural lands (BERARDY; CHESTER, 2017; MPANDELI et al., 2018; PERRONE; HORNBERGER, 2016). The human action, urbanization and the need of access to natural resources essentials to human and environmental survival intensify the debate over the well management of water, energy and food (GONDHALEKAR; RAMSAUER, 2017; TOPI; ESPOSTO; MARINI GOVIGLI, 2016; WALKER et al., 2014). It is a primary challenge to the WEF Nexus approach, therefore, to securitize access in quantity and quality of water, energy, food and sanitation (HOFF, 2011; LEESE; MEISCH, 2015).

The need for WEF security is in the core of WEF Nexus Thinking (BIBA, 2016; DE LAURENTIIS; HUNT; ROGERS, 2016; HOFF, 2011; ZHANG; VESSELINOV, 2017). In its constructivist root, security is a construct that can emerge from a threat (BUZAN; WÆVER; DE WILDE, 1998; LEESE; MEISCH, 2015). In a natural resources context, the need for security is the need for access to resources that are increasingly expensive and scarce. Nevertheless, the literature has argued that the well management and adaptation of these resources, through a WEF Nexus approach, is possible and may guarantee water, energy and food access security (HOFF, 2011; LEESE; MEISCH, 2015; RASUL; SHARMA, 2016).

Aiming to achieve Sustainable Development, the United Nations proposed, in 2015, The 2030 Agenda for Sustainable Development, with 17 Sustainable Development Goals and 169 targets. Some of these goals have close relation to the WEF Nexus and are explored by literature, even though not explicitly, such as the goals related to end of poverty (BIGGS et al., 2015; VLOTMAN; BALLARD, 2014), end of hunger (DE LAURENTIIS; HUNT; ROGERS, 2016; VLOTMAN; BALLARD, 2014), clean water and sanitation (VOULVOULIS, 2012), affordable and clean energy (CHEN; ZHANG, 2015; ZHANG, 2013), sustainable cities and communities (GONDHALEKAR; RAMSAUER, 2017; HEARD et al., 2017; WALKER et al., 2014), responsible consumption and production (EL-GAFY; GRIGG; REAGAN, 2017; VLOTMAN; BALLARD, 2014), climate action (BERARDY; CHESTER, 2017; NHAMO et al., 2018; ZHANG X. et al., 2018) life bellow water (GRAHAM; PUEPPKE; UDERBAYEV, 2017) and life on land (INTRALAWAN et al., 2018; STOSCH et al., 2017). These goals can be achieved through business, public policies, society and organizations.

Seen as a lens to comprehend and manage the dichotomy of scarce resources and population growth, a WEF Nexus approach can establish a new paradigm as a way for achieving sustainable growth and sustainable development (KURIAN, 2017; SMAJGL; WARD; PLUSCHKE, 2016). The concept and approaches of WEF Nexus Thinking are deeper explored in the results of a systematic literature review presented Section 4.

2.2 Sustainable Business Model and its elements

The idea of the conceptualization of business models found wide receptivity specially from the 1990's dotcom businesses boom (GEISSDOERFER; VLADIMIROVA; EVANS, 2018; RICHARDSON, 2008). The description of the elements of the firm, and the way the company can propose and capture value from the customers were a very appealing way for attracting new investors in the early phases of e-commerce. Business models can be described as a simple depiction of the elements of the firm that propose, create and deliver and capture value, as well as the interactions between these elements and activities in the business unity, through the development and usage of business opportunities (GEISSDOERFER; VLADIMIROVA; EVANS, 2018; ZOTT; AMIT, 2010). In the field of study of Business Models strategy, one way of structuring and design a business model is through an integrative and dynamic framework composed by three elements: Value Proposition, Value Creation and Delivery System and Value Capture (RICHARDSON, 2008).

The increase of institutional and regulatory pressure for environmental and social awareness by companies forced the creation of new business models, with a concern on sustainable goals (CONNELLY; KETCHEN; SLATER, 2011). Despite of this need for embodying sustainable concerns to business elements and routines, currently, Sustainable Business Models present themselves as a source of competitive advantage (MORIOKA et al., 2018). Instead of denying the traditional view of Business Models, Sustainable Business Models represent a way of complementing and surpassing the business-as-usual Business Models concept (GEISSDOERFER; VLADIMIROVA; EVANS, 2018; MORIOKA et al., 2018).

Analogically to traditional Business Models, Sustainable Business Models can be structured upon three main elements: Value Proposition, Value Creation and Delivery System and Value Capture (BOCKEN et al., 2014; MORIOKA; BOLIS; CARVALHO, 2018; RICHARDSON, 2008).

First, the Value Proposition represents the company's reason of being (RICHARDSON, 2008). The Value Proposition of a firm is also represented by its services and products. Considering Sustainability, Sustainable Value Proposition encompasses economic, but also socio-environmental values (MORIOKA; BOLIS; CARVALHO, 2018).

Second, the Value Creation and Delivery System is structured by firm's routines, resources and capabilities. Sustainable Value Creation and Delivery System considers firms operations and capabilities that may put in practice routines that can deliver the Sustainable Value proposed (MORIOKA; BOLIS; CARVALHO, 2018). Sustainable value creation has to do with routines, practices and activities that will create and delivery financial, social and economic value, not only to customers, but also for various stakeholders (LAUKKANEN; TURA, 2020; MORIOKA; BOLIS; CARVALHO, 2018).

Third, traditional business model literature consider Value Capture as the financial return of a firm's value creation and delivery system (OSTERWALDER; PIGNEUR;

TUCCI, 2005). When it comes to the idea of Sustainable Business Models, value capture can be understood by the value captured by each stakeholder connected direct or indirectly to the focal organization as social contribution and environment protection (MORIOKA et al., 2018; MORIOKA; BOLIS; CARVALHO, 2018). These stakeholders, in their turn, can create and deliver sustainable value that can be captured by indirect stakeholders, that not necessarily has a straight link to the firm. This indirect value capture can be referred as cascaded value capture (MORIOKA et al., 2018).

In this new logic of sustainability as a source of competitive advantage for the company, Sustainable Business Models are challenged not only to transcend sustainability challenges, but also to outperform business-as-usual models, through business model innovation (MORIOKA et al., 2018). Business model innovation can be understood as the development and implementation of new business models (GEISSDOERFER; VLADIMIROVA; EVANS, 2018).

The main rationale behind business model innovation is that it will change one or more of business model components (Value Proposition, Value Creation and Delivery System and Value Capture) (KARLSSON et al., 2016; RICHARDSON, 2008). Routing a business model innovation process can be a hard task due the complexity of challenges and activities involved in the path (GEISSDOERFER; SAVAGET; EVANS, 2017; GEISSDOERFER; VLADIMIROVA; EVANS, 2018; KARLSSON et al., 2016). Some authors argue that, in practice, companies (specially small and average market players) typically have an organic way of innovating (EVANS; RANA; SHORT, 2014; LAUDIEN; DAXBOECK; DAXBÖCK, 2017). Nevertheless, some of the business model innovation processes founded in literature are listed in Table 1.

Table 1 - Business Model Innovation Process

<table>
<tr><th>Reference</th><th>BMI Process Framework</th><th colspan="3">Concept Design</th><th colspan="3">Detail Design</th><th colspan="2">Implementation</th></tr>
<tr><td>Schallmo (2013)</td><td>Generic BM Innovation Process</td><td>BM Recovery Ideas</td><td colspan="2">Visions for the development of BM</td><td colspan="2">BM Prototype Development</td><td>BM Development</td><td>BM Implementation</td><td>BM Improvements</td></tr>
<tr><td>Frankenberger et al. (2013)</td><td>The 4I-framework of BM innovation</td><td>Initiation</td><td colspan="2">Ideation</td><td colspan="3">Integration</td><td colspan="2">Implementation</td></tr>
<tr><td>Evans; Rana; Short (2014)</td><td>Sustainable BM Innovation Process</td><td>Setting the scene</td><td>Value Mapping</td><td>Idea Generation</td><td colspan="3">BM or solution(s) selection</td><td colspan="2">Configure and Coordinate</td></tr>
<tr><td>Laudien; Daxböck (2017)</td><td>Average Market Players Innovation Process</td><td colspan="3">Monitoring the BM fit beyond the industry-level</td><td colspan="3">BM Development</td><td>Opening up the BM</td><td>Deliberate BM innovation</td></tr>
<tr><td>Geissdoerfer; Savaget; Evans (2017a)</td><td>Cambridge BM Innovation Process (CBMIP)</td><td>Ideation</td><td>Concept Design</td><td>Virtual Prototyping</td><td>Experimenting</td><td>Detail Design</td><td>Piloting</td><td>Launch</td><td>Adjustment & Diversification</td></tr>
<tr><td>Antikainen et al. (2017)</td><td>BM innovation process in AARRE-project</td><td>Understanding the current BM</td><td colspan="2">Understanding future BM environment</td><td colspan="3">Future customer understanding</td><td>Business Opportunity Exploration</td><td>Real Data on the BM</td></tr>
<tr><td>Mentink (2014)</td><td>The Circular BM Innovation Framework</td><td>Preparation</td><td>Initiation (Analysis)</td><td>Ideation</td><td colspan="3">Integration</td><td colspan="2">Implementation</td></tr>
<tr><td>Roome; Louche (2016)</td><td>BM Change for Sustainability</td><td colspan="3">Identifying</td><td colspan="3">Translating</td><td>Embedding</td><td>Sharing</td></tr>
</table>

Although distinct processes present different descriptions and number of phases, the majority can be divided in three broader groups: Concept Design, Detailed Design and Implementation (GEISSDOERFER; SAVAGET; EVANS, 2017; SCHALLMO, 2013).

First, in the phase of Concept Design, the business model current situation is analyzed and the main value proposition, key stakeholders and main concepts are ideated (EVANS; RANA; SHORT, 2014; GEISSDOERFER; SAVAGET; EVANS, 2017). Second, in the phase of Detail Design, the new business model (BM) prototyping and experimentation can be put into practice, and the main solutions to the Value proposed can be planned (EVANS; RANA; SHORT, 2014; GEISSDOERFER; SAVAGET; EVANS, 2017). In this detailing phase, questions as "Who?", "What?", "How?" and "Why?" should be answered (FRANKENBERGER et al., 2013).

The third phase commonly present in the business model innovation processes described in the literature is "Implementation". Generically, this phase comprehends the business model innovation itself and future adjustments (GEISSDOERFER; SAVAGET; EVANS, 2017). In this phase the business model innovation is explored, measured and improved (ANTIKAINEN et al., 2017; SCHALLMO, 2013). Evans, Rana and Short (2014) argue that the implementation phase is not the last phase in the innovation process; this is a continuous routine. Rather, it is an organic process, and needs to be more explored.

Although many tools have been developed to help companies to conceptualize and design innovation (e.g. GEISSDOERFER; BOCKEN; HULTINK, 2016; TÄUSCHER et al., 2017), not all companies succeed in the innovation implementation and boosting (GEISSDOERFER; SAVAGET; EVANS, 2017). This deficiency in the implementation is called implementation-gap, and is defined as "…a gap between conceptualization and implementation that leads to promising ideas not being further investigated, concepts not being implemented, and implemented business models failing in the market." (GEISSDOERFER; SAVAGET; EVANS, 2017, p. 263).

A systematic literature review conducted by Pieroni, Mcaloone and Pigosso (2019) about Innovation for Circular Economy BMs verified that from the sample studied, only 20% of the innovation approaches addressed the implementation phase. Moreover, there is a gap in literature concerning the challenges and activities companies face in the implementation phase when innovating their business models (GEISSDOERFER; VLADIMIROVA; EVANS, 2018). According to Mentink (2014), the number of challenges of implementation phase pointed out by literature is greater than any other challenges of other phases of business model innovation process. It is necessary, therefore, to identify the main challenges companies can face during business model innovation process to become more sustainable; in particular, to become a business model aligned to WEF Nexus principles. The main challenges found in literature are summarized in Table 2.

Some of the challenges found in literature are related to the entrepreneur and/or manager of the business mind-set and vision. Fear of changes and attachment to the current way of doing business can hinder the innovation implementation (BJÖRKLUND, 2018; CHESBROUGH; ROSENBLOOM, 2002). Similarly, the business leadership style is a determinant factor to the success of innovation implementation. More conservative leaders tend to inhibit the innovation designed (ABEBE; MYINT, 2018). A siloed thinking, that hinder an integrative approach to face challenges, can also obstruct more efficient and unified innovation (DAHLMANN; BULLOCK, 2020).

Changes in products, services, technology and business models will generally awake competitive imitation (CASADEUS-MASANELL; ZHU, 2013). Business model entrepreneurs and managers should measure innovation risk and decide whether is secure to reveal innovation through a new business model or conceal innovation from competitors (CASADEUS-MASANELL; ZHU, 2013; DESYLLAS; SAKO, 2013).

The risk of context and technology disruptive changes also can be a challenge to innovation implementation (GHEZZI; CORTIMIGLIA; FRANK, 2015). Moreover, the new product/service offered can suffer problems of acceptance, lack of demand and affordability (BJÖRKLUND, 2018; NAOR; DRUEHL; BERNARDES, 2018). According to Mohtar (2017), new business models aligned with Nexus Thinking need to focus on four main pivoting levers: (1) create synergy between Nexus nodes (WEF) and, ironically at the same time, (2) reduce WEF interdependences by mitigating possible trade-offs, (3) improve equity and distribution and (4) ensure WEF security. In order to promote Sustainability towards a WEF Nexus Thinking through new business models, it is necessary innovation in the existing business models or the creation of new ones aligned with WEF Nexus Thinking. In this sense, technological innovation towards a WEF Nexus Thinking can improve businesses outputs without maximizing natural resources inputs (RINGLER; BHADURI; LAWFORD, 2013).

Table 2 - Business Model Innovation Challenges

Challenges	Description
Mind-set related challenges: **Attachment to traditional way of doing business, cognitive barrier, leadership, restrictive and siloed mind-set and ecological-philosophical considerations and socioemotional wealth**	- The dynamics of business model innovation can "conflict with more tradition configurations of firm assets" (CHESBROUGH, 2010, p. 358) - "Cognitive barriers restrict new ideas that do not fit with the firm's current business model" (RICHTER, 2013, p. 1235); - The style of leadership can drive or hinder a business model innovation implementation. - A restrictive mind-set can increase apprehension to make changes in the current business model and embarrass self-leadership (BJORKLUND; BJÖRKLUND, 2018); - "The ecological philosophical considerations create barriers, for example, based on inherited cultural and rural values" (BJÖRKLUND, 2018, p. 81); - "Socio-emotional wealth describes a barrier that is the result of a focus on family needs and values instead of the attainment of financial goals" (BJÖRKLUND, 2018, p. 81). - Business difficulty to face challenges as integrated and recognize interdependences between sustainability challenges (DAHLMANN; BULLOCK, 2020; RANTALA et al., 2018)
Opportunity Cost	- The innovation towards a new Business Model involves the opportunity cost of cannibalizing existing assets, firm's businesses and competences (DESYLLAS; SAKO, 2013)
Lack of competences and communication issues	- "…lack of competences with respect to strategic management, organization, and self-leadership" (BJORKLUND; BJÖRKLUND, 2018, p. 80) - The difficulty of communication can compromise the innovation process (GEISSDOERFER; SAVAGET; EVANS, 2017)
Insufficient resources	- "Insufficient resources refer primarily to the entrepreneurs' lack of adequate financing" (BJORKLUND, BJÖRKLUND, 2018, p.81; DESYLLAS; SAKO, 2013; GEISSDOERFER; SAVAGET; EVANS, 2017).
Disruptive changes	- The risk of business model innovation can increase in environments of disruptive ecological, technological and regulatory changes (CASADEUS-MASANELL AND ZHU; 2013; DESYLLAS AND SAKO; 2013).
Imitation	- New Business Models can suffer imitation and lose competitive advantage (GHEZZI; CORTIMIGLIA; FRANK; 2015).
Resistance or lack of support from actors and government	- Large scale production and conglomerates and customer behavior changes can be a barrier to business model innovation implementation. - Government regulatory pressures can limit the scope of changes (BJÖRKLUND, 2018).
Inadequate timeframe/expectation	- The time for innovation is not the best. - The innovation process behaves differently from expected (GEISSDOERFER; SAVAGET; EVANS, 2017).
Transition Time and dependence degree on the original business model	- "New business models … need an independent organizational setting to support it" (BROEKHUIZEN; BAKKER; POSTMA, 2018, p. 559; RICHTER, 2013a)
New product challenges: Affordability and new product technology and lack of demand	- New business models can face the challenge of price and affordability of new products and services.

	- Technological innovations can face challenges related to new technology acceptance, availability and affordability (NAOR; DRUEHL; BERNARDES, 2018; RICHTER, 2013A; 2013B).
Social Environmental Consequences Projection	- Businesses can struggle in projecting social and environmental consequences to technological innovation (LONG; BLOK; POLDNER, 2017)
Value Proposition and Value Creation and Delivery System Design	- Businesses can design and project future value capture, neglecting Value Proposition and Value Creation and Delivery System Design (BOHNSACK; PINKSE; KOLK, 2014; KHAN; BOHNSACK, 2020; LAUDIEN; DAXBOECK; DAXBÖCK, 2017)

Particularly in the field of food production, the implementation of new technologies, aiming to increase water, energy and food synergies and decrease their trade-offs can be a possible path to surpass innovation challenges and enable business model innovation.

Beyond the anticipated outcomes in crop productivity, technology implementation has significant positive and negative implications to the business model itself as well to various stakeholders (ADEBIYI et al., 2020; MENEGUZZO et al., 2019). Therefore, firms need to project Social and Environmental consequences to their technology implementation (LONG; BLOK; POLDNER, 2017). Further, positive impacts of technology implementation can be minimized if firms do not project and redesign Value Proposition and Creation and Delivery System (BOHNSACK; PINKSE; KOLK, 2014; KHAN; BOHNSACK, 2020; LAUDIEN; DAXBOECK, 2016). For a deeper understanding of these implications it is necessary, first, understand how technology aligned with WEF Nexus Thinking implementation affects business models in agribusiness.

3. RESEARCH METHODS

The research methodology encompasses two main macro stages: a Systematic Literature Review (SLR) on WEF Nexus and case studies. The technique of SLR was selected due the construct complexity. For systematic literature reviews, it is expected that robust and solid results and evidences emerge, with the potential of transfer across different backgrounds (DENYER; TRANFIELD, 2009).

The second macro stage is related to case studies. Multiple exploratory case studies were conducted with the aim of exploring the research areas and theory building (EISENHARDT, 1989; YIN, 2009). The SLR helps to meet the SO#1, whereas the case studies aim to meet SO#2 and SO#3. Each stage is further described following (Sections 3.1 and 3.2).

3.1 Procedures to the Systematic Literature Review on WEF Nexus

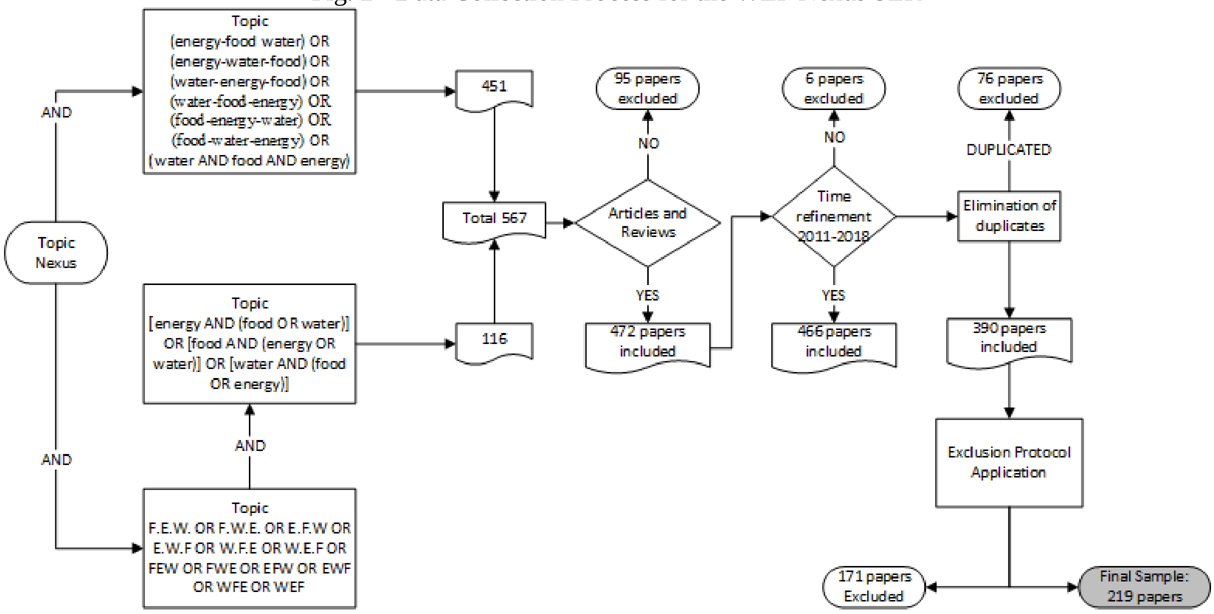
In this section, the procedures to the conduction of the systematic literature review on WEF Nexus are presented. A SLR was conducted, since it aims to collect, organize, map, inform, analyze and synthesize the main research topics and trends in a given research area (DENYER AND TRANFIELD, 2009; ROWLEY ET AL., 2004; TRANFIELD ET AL., 2003).

Different from other methods of reviews, SLRs adopt a replicable, scientific and transparent process (DENYER; TRANFIELD, 2009; ROWLEY; JENNIFER; SLACK, 2004; TRANFIELD; DENYER; SMART, 2003). In order to ensure the technical rigor required from a systematic literature review, the five steps presented by Denyer and Tranfield (2009), were followed and will be described as it follows: (1) question formulation, (2) locating studies, (3) study selection and evaluation, (4) analysis and synthesis and (5) reporting and using the results. The step 1 from the procedures was reported in the Chapter 1 of this research.

For step 2, the main keywords used in most of publications on WEF Nexus in literature were identified in an initial exploratory literature review. The online database selected was the ISI Web of Science data base, for its relevance in the academic field and interdisciplinarity. Moreover, the results from search in this database comprises publications from indexed journals (including from other databases such as Emerald and

Scopus), with impact factor considered (Journal Citation Report – JCR). Main research strings, data collection process, and inclusion/exclusion criteria are summarized in Fig. 2.

Fig. 2 - Data Collection Process for the WEF Nexus SLR



For the step 3 of the procedures above mentioned (DENYER; TRANFIELD, 2009), a study selection and evaluation was made. To guarantee greater methodological rigor for the systematic literature review, only articles and reviews (peer-reviewed papers) were selected. From the 567 papers founded in the search, 472 were article and review. Therefore, 95 papers were excluded from the sample. Furthermore, only studies after the Bonn2011 Nexus Conference were included in the sample, since its publication "Understanding the Nexus. Background paper for the Bonn2011 Nexus Conference" is considered a seminal paper for the Nexus Literature (BENSON; GAIN; ROUILLARD, 2015; OZTURK, 2017; SMAJGL; WARD; PLUSCHKE, 2016). Thus, 6 papers were excluded. From the 466 remaining papers, 76 were duplicated and, thus, excluded. After the elimination of duplicate papers, the sample size was 390. Only papers published until July, the 3rd, 2018 were considered, as it was the date on which the search in the database was performed. The exclusion criteria used in the SLR were (a) papers that address other types of Nexus approaches than WEF Nexus (e.g., water-energy nexus, water-land nexus, energy-food nexus, etc.) and (b) papers that does not address directly the WEF Nexus issue; just mention it during the text. This exclusion criterion was established as a way for guaranteeing the focus on the research scope. After the application of the exclusion protocol, the final sample was composed by 219 articles and reviews.

The fourth step of the review comprehends summarizing the evidences from the literature. For this, a logic from a more general overview of the literature towards the identification of the specific WEF Nexus principles to support case study operationalization was followed using three sub-steps. This was necessary to enable gradual accumulation of knowledge on the literature, necessary to reach the aimed WEF Nexus principles (SO#1). The first is the quantitative analysis of the literature composed of descriptive statistics and network analysis. Sample data were imported to electronic spreadsheets, as also performed by prior reviews (CALDERA; DESHA; DAWES, 2018; RODRIGUES; MENDES, 2018). Further, descriptive statistics and analyses were conducted, presenting the distribution of publications over the years, main journals of the sample and most cited papers, following previews systematic literature reviews in the field of sustainability (HOMRICH et al., 2018; JIA; JIANG, 2018; MORIOKA; DE CARVALHO, 2016). The network analyses (co-citation, cited references, and co-occurrence – authors keywords – maps) were developed with the support of VOSViewer Software (VAN ECK; WALTMAN, 2010). Section 4.1 presents associated results from this sub-step.

The second sub-section is a content analysis of the articles in terms of subjects addressed by each research. Content analysis technique allows replicable and valid inferences from the text (WHITE; MARSH, 2006). A qualitative approach was adopted in the textual analysis, in an inductive way. (ELO; KYNGÄS, 2008). Within inductive studies, the categorization can emerge from the data and research question, when the body of knowledge might seem fragmented (ELO; KYNGÄS, 2008). The codes emerged after in-depth analysis including reading, interpretation, semantic convergence analysis and thematic categorization of each paper from the samples (BARNETT-PAGE; THOMAS, 2009; THOMAS; HARDEN, 2008). Following this coding strategy, two rounds of coding were carried out. First, the articles from the sample were grouped based on the main subjects addressed by each paper from the sample. This led to the first order categories of codes. Afterwards, this grouping of codes was refined in the second order of coding, and the articles were clustered according to the main constructs and patterns emerged from the papers composing each first order coding category. Section 4.2 presents description of these categories.

After a better understanding of the literature on WEF Nexus in a more general way in terms of its characteristics and research subjects, the third sub-step was focused on attempting of better delimitation of the concept of WEF Nexus, by proposing associated WEF Nexus principles. In an inductive way, the subjects and themes were aggregated in groups from which it would be possible to identify the presence or intention of a WEF Nexus perspective. Section 4.3 presents description of the ten WEF principles identified from literature analysis. These principles served to support specific object #2, was explained in the following Section (3.2).

3.2 Procedures for Case Studies

In a qualitative approach, this research follows a case study design. This research strategy is useful to understand a real-life event, within specific settings (EISENHARDT, 1989; YIN, 2009). In this particular situation, case study is likewise appropriate because it allows more in-depth analysis of qualitative data for building theory (EISENHARDT, 1989; VOSS; TSIKRIKTSIS; FROHLICH, 2002). In a parallel way, this study has also an exploratory character, since the case study can lead to unknown research questions and results (VOSS; TSIKRIKTSIS; FROHLICH, 2002).

For the conduction of case studies, first the theoretical and conceptual basis was defined (YIN, 2009). The next step is the case selection (EISENHARDT, 1989). Case selection is an important aspect of case studies (EISENHARDT, 1989). The units of analysis selected can be chosen to fill categories or provide examples of polar types (EISENHARDT, 1989). As the research question revolves around understanding how technology aligned with WEF agribusiness business models, seven technologies, from four different companies, were chosen as case studies units of analysis. For case selection, it was taken in consideration if the firm has implemented technological innovation aligned with WEF Nexus Thinking.

For technology selection, the goal of water and energy efficiency to food production was considered as a criterion, as Water, Energy and Food Security is an idiosyncratic feature of WEF Nexus. Table 3 presents information about case study units.

Appendix A presents the Research Protocol, important to ensure case study reliability (YIN, 2009). According to Yin (2009), the research protocol must contain the case studies questions, hypotheses and the theoretical framework studied in case study and serves to guide researchers during the conduction of case study. For data collection, in-depth, semi structured interviews were conducted (script in Appendix B). Questions in the script were formulated in order to better capture interviewees' perceptions about the technology analyzed and the impact on the business model.

Table 3 - Case Study Units of Analysis

Firm	Type Of Technology	Main activities	Analyzed Technology	Unit of Analysis	Interviewee
A	Irrigation	Fruit Producer and Exporter	Dendrometric evaluation system as an indicator for plantation irrigation management	A1	President/Owner
	Water Reuse		Sewage treatment	A2	
Firms A and B	Water Reuse		Packing house water reuse	AB1	
B	Irrigation	Fruit Producer, Distributor and Exporter	Micro Splinker Irrigation	B1	President/Owner
C	Clean Energy	Fruit Producer and Distributer	Solar based energy for irrigation	C1	Sales Director
	Semi-Hydroponics Cultivation		Semi Hydroponics strawberry cultivation	C2	
D	Microalgae biomass	Agroecological Fruit and animal producer	Microalgae biomass production for integration in organic food farming integrated biosystems	D1	Project Manager (Researcher)

A qualitative approach was employed in data analysis, through content analysis. This research method is useful for making replicable and valid inferences about some real life event (ELO; KYNGÄS, 2008). For this, interviews were transcribed, codified and tabulated. Codification units emerged from the Systematic Literature on WEF Nexus literature review on Sustainable Business Models.

Table 4 presents the codes used in content analysis, divided in four broader groups of codes. The first regards the WEF Nexus Principles, resulted from achieving the specific objective #1 and better explained in Section 4.3. The other three consider the SBM elements described in Section 2.2: Value Proposition, Value Creation and Delivery System, and Value Capture. Interviewees' statements were codified, tabulated and compared. First, in a within-case analysis, the alignment of case study units with the WEF

Nexus Principles were examined and discussed. Second, a cross-case analysis enabled the identification of patterns and peculiarities between cases. This dual analysis approach is useful to recognize patterns and compare with theory (EISENHARDT, 1989).

Table 4 – Case Studies Content Analysis Codes

WEF Nexus Principles	Water, Energy and Food Security	**Value Proposition**	**Value Creation and Delivery System**	Supply Chain & Logistics	**Value Capture**	Shareholders/Investor
	Resources Efficiency			Operations		Employees
	Resources Reuse			Marketing & Sales		Customers
	Access/Livelihood			Innovation, R&D		Suppliers/Partners
	Multi-Stakeholder Consideration			Organizational Culture		Society
	Local, Regional, Global Scales			Corporate Governance		Environment
	Sustainable Cities					Government
	Clean Technology					Competitors
	Resilience					

Lastly, results discussion was carried out in light of WEF Nexus and Sustainable Business Model literature, and some implications of technology implementation for Sustainable were addressed.

4 RESEARCH RESULTS FROM THE SYSTEMATIC LITERATURE REVIEW

This section aims to meet the first research specific objective, which is “to identify WEF Nexus Principles”. Thereunto, this section was divided into two subsections. In 4.1 a general overview of literature is presented, with descriptive and network analyses of the sample. Subsection 4.2 brings a sample content analysis, and delimitation of WEF Nexus Principles.

4.1 General Overview of the Literature

The 219 papers from the sample (Fig. 3) were published between 2011 ((BAZILIAN et al., 2011) - the same year of the Bonn Conference (HOFF, 2011) - and 2018 (data collection year). Theis abrupt increase from 2014 (5 papers published) to 2015 (44 papers published) may be explained partially by the Special Issues published in the latter year. From the 44 articles published in 2015, 26 were from special issues (Journals: Water, Water Alternatives, Water International and International Journal of Water Resources Development). The publication of Special Issues could indicate a relevant and growing interest of specialized journals and scientific community for the WEF Nexus.

Fig. 3 - Publications per year

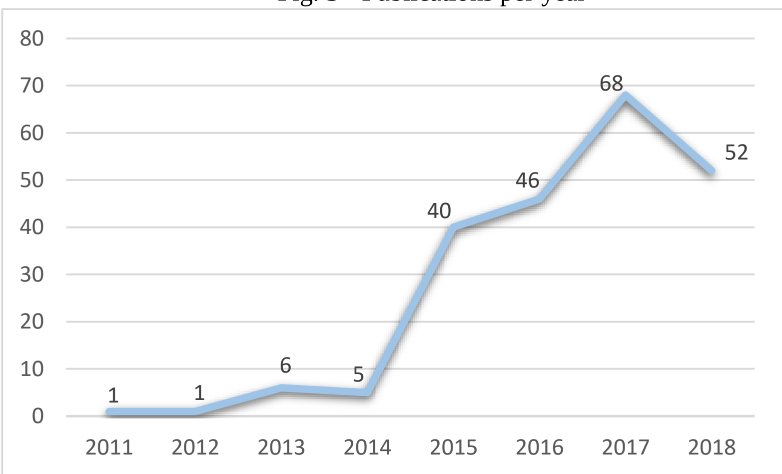


Table 5 shows the main journals that publish on WEF Nexus, with their ISI Journal Citation Report. The JCR Impact Factor of all of them is higher than 1.00, indicating a high relevance of these journals to academic research. The journals Water, International Journal of

Water Resources, Water International and Water Alternatives have a focus more directed to water policy, management, development and governance issues. Environment Science and Policy deals with policy in climate change, biodiversity, pollution, waste, sustainability (economic and social). The journals Environmental Science and Policy, Current Opinion in Environmental Sustainability, Journal of Cleaner Production, Environmental Research Letters and Environmental Progress & Sustainable Energy are transdisciplinary journals with a focus on sustainability. Current Opinion in Chemical Engineering publishes aim attention at chemical issues as bioenergy and biotechnology.

Table 5 – Sample Main Journals

Journal	**JCR**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**Total**
Water	2.069				6	5	4	5	20
Environmental Science and Policy	3.826			1	1	5	5	1	13
Int. Journal Of Water Resources Development	1.825	1			6	2	1		10
Water International	1.956				8		1		9
Current Opinion In Chemical Engineering	4.186						7		7
Current Opinion Environmental Sustainability	5.651		2		1	4			7
Journal Of Cleaner Production	4.541					2	2	3	7
Environmental Progress & Sustainable Energy	4.033							7	7
Environmental Research Letters	2.647					2	4	1	7
Water Alternatives	1.326				7				7
Total		1	2	1	29	20	24	17	94

Table 6 presents a list with the most cited papers, their objectives, number of citations and average of citations per year. The most cited paper, Bazilian et al. (2011), is the oldest article in the sample, published at the same year of Hoff (2011), for the Bonn Conference. It is natural that this paper has the highest number of citations in the sample. However, it is still remains a relevant paper, as it has the highest average citations in the sample. Ringler et al. (2013) discuss the importance of considering land issues in the WEF Nexus perspective, engaging multiple sectors for improving resource efficiency. Rasul (2014) and Conway et al.

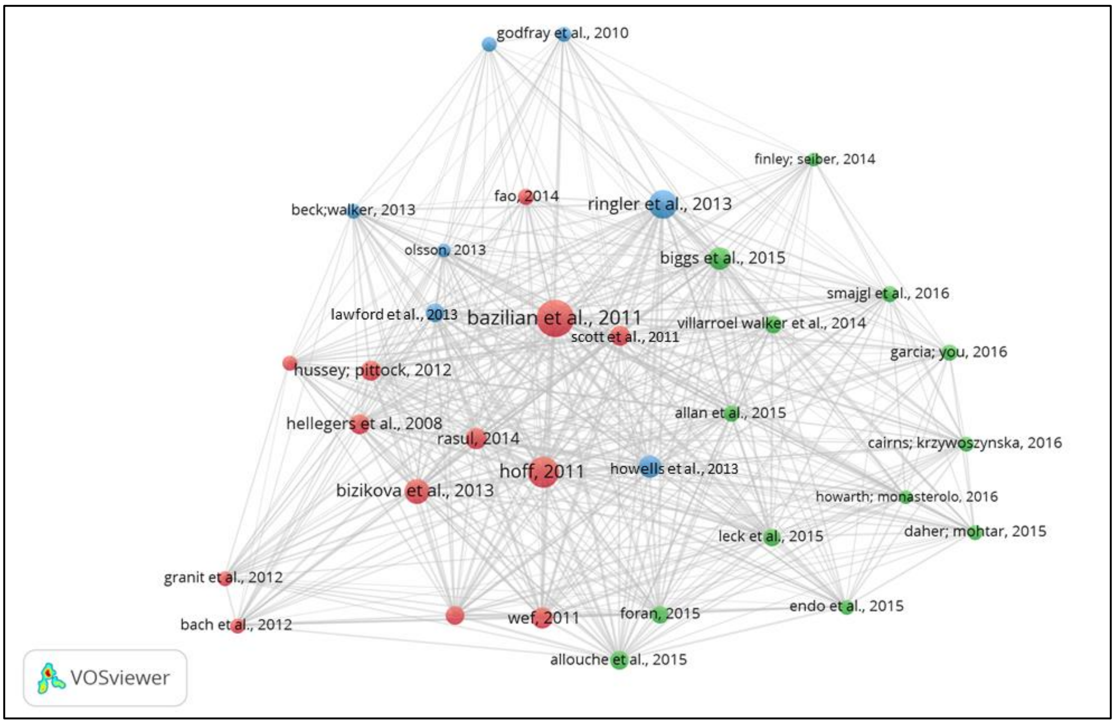
(2015) discuss the WEF Nexus in a regional context, highlighting the need of an integrated approach for assessing and managing the WEF Nexus in a regional specific context. The research of Biggs et al (2015) argues the need of incorporating sustainable livelihood perspectives to the WEF Nexus as a tool to achieve sustainable development. Benson et al. (2015) questions the efficiency of water governance in a WEF Nexus perspective, comparing with the preexisting models of Integrated Water Resources Management (IWRM). Garcia and You (2016) highlight research challenges for the Process Engineering field in the WEF Nexus context and Walker et al. (2014) explore the resource fluxes and efficiency in a urban perspective. Leck et al. (2015) explore emerging trends and challenges in Nexus agenda. The research of Lawford et al. (2013) considers major factors of the WEF Nexus in a basin context. Many publications in the WEF Nexus literature address river basin biomes (e.g. Granit et al., 2012; Karabulut et al., 2016; Mayor et al., 2015; Soliev et al., 2015; Verhoeven, 2013).

Table 6 - Most Cited Papers about WEF Nexus Thinking

Autor	**Objective**	**Total Citations**	**Average Citations per year**
Bazilian et al., 2011	To describe interconnections between Nexus issues; to point to some directions for addressing the nexus and to propose a modelling framework that can support policy and regulatory design.	269	29.89
Ringler et al., 2013	To discuss main concepts about water, energy, landy and food Nexus, its interlinkages, trade-offs and the need of improved resource use efficiency.	125	17,86
Rasul, 2014	To explore “the food, water, and energy nexus from a regional dimension, emphasizing the role of Hindu Kush Himalayan (HKH) ecosystem services in sustaining food, water, and energy security downstream.” (p. 36-37).	94	15.67
Biggs et al., 2015	To review nexus approaches in a livelihood perspective.	90	18.00
Benson et al., 2015	To review the Nexus Literature to determine some common indicative criteria and compare with more established IWRM models.	71	14.20
Conway et al, 2015	To discuss the impacts, interconnections and solutions for the climate issue on Southern Africa WEF Nexus, considering economic and policy aspects.	57	11.40
Garcia; You, 2016	To highlight “research challenges and identify process systems engineering research opportunities to appropriately model and optimize the WEF Nexus.” (p. 49)	52	13.00
Walker, et al., 2014	To describe and apply a quantitative approach to the analysis of urban metabolism exploring three objectives: to estimate resource flows entering, leaving and circulating within the city; to reveal the synergies and antagonisms amongst options for reducing water use and the recovery of energy and nutrients as a result of infrastructure changes; to estimate the monetary value of the additional revenue and expenditure reductions that arise from implementing four candidate technologies.	50	8.33
Leck et al., 2015	“to provide a source of reference on recent developments in what remains an emerging agenda” (p. 446)	49	9.80
Lawford et al., 2013	“To summarize some major factors that influence the Water-Energy-Food (W-E-F) Security Nexus and how they are perceived in different basins.” (p. 607).	37	6.17

With the purpose of understanding the research streams in the sample, bibliometric mapping and analyses were performed with the VosViewer Software (VAN ECK; WALTMAN, 2010). The first network performed was the Co-Citation Map of Cited References (Fig. 4). With a minimum of 12 citations of a cited reference, 33 cited references met the threshold, which constituted three clusters.

Fig. 4 - Co-citation Network - Cited references



In the center, the most relevant paper is Bazilian et al. (2011), in the first cluster (red). This cluster is composed mainly by seminal references addressing WEF Nexus (BACH et al., 2012; BAZILIAN et al., 2011; FAO, 2014; HELLEGERS et al., 2008; HOFF, 2011). In 2008, Hellegers et al. (2008) address the interactions between water, energy and food resources. In 2011, the Bonn2011 Conference (HOFF, 2011) became the first event internationally recognized with a focus on WEF Nexus (see Benson et al., 2015). In this network center, there is also the research of Scott et al. (2011), addressing the Nexus between water and energy, in the beginning of WEF Nexus concept popularization. Many publications in this cluster has the intention of debating issues about the Nexus philosophy and discourse.

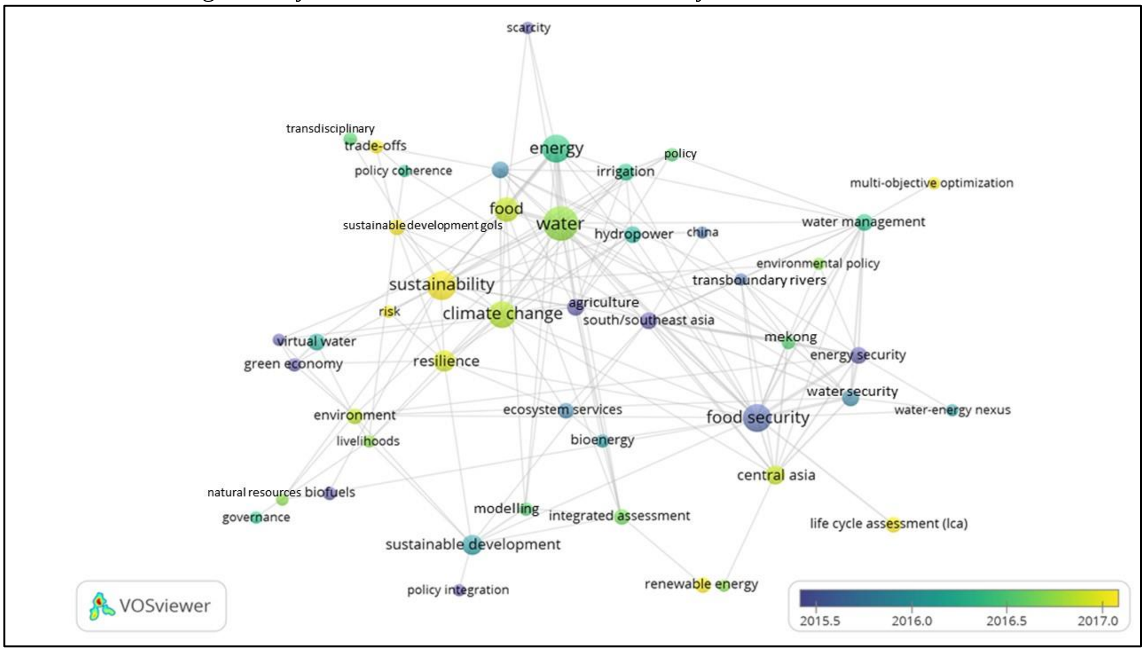
The most prominent reference represented in the second cluster (green) is Biggs et al. (2015), which discusses Sustainable Development and WEF Nexus from a livelihood perspective. The papers inserted in this cluster are the most recent ones in the map (average publication year: 2015). Some papers address Nexus assessment and analysis (DAHER; MOHTAR, 2015; ENDO et al., 2015; FORAN, 2015). The researches of Allan et al. (2015), Allouche et al. (2015), Cairns and Krzywoszynska (2016), Finley and Seiber (2014), Leck et al. (2015) and Smajgl et al. (2016) explore Nexus interconnections, approach and concepts.

In the third cluster (blue), the average publication year is 2012. Many publications in this cluster focus on resource management: climate (BECK; VILLARROEL WALKER, 2013; HOWELLS et al., 2013), land (HOWELLS et al., 2013; RINGLER; BHADURI; LAWFORD, 2013), food security (GODFRAY et al., 2010), and water security (LAWFORD et al., 2013). Olsson (2013) explores the interactions between water, energy and food resources. With an approach of Water-Energy-Food-Land Nexus, Ringler et al. (2013) is the most relevant reference in this cluster, with the most stronger connection with other references.

Since all the articles in the sample are connected to "WEF Nexus", this keyword and its variations were excluded from the map for keyword co-occurrence analysis (Fig. 5) in order to allow a better visualization. With at least 3 occurences of a given keyword, 46 words met the threshold.

In a time overlay visualization, it can be verified that keywords related to water, energy and food security, transboundary rivers, South/Southest Asia, China are the oldests occurences in the map (average publication year: 2015). It could be explained by the multiplicity of studies about resource management in transboundary river basins (BELINSKIJ, 2015; FORAN, 2015; SMAJGL; WARD; PLUSCHKE, 2016). In this context, attention has been paid specially to Mekong River Basin (BACH et al., 2012; KESKINEN et al., 2015), partcularly considering China as a riparian country (LI; HUANG; LI, 2016; MATTHEWS; MOTTA, 2015).

Fig. 5 - Keywords Co-occurrence - Time Overlay Network Visualization



With a more recent publication avarege year, the presence of keywords as “risk”, “resilience”, “livelihood” and “trade-offs” manifest a trend in literature to explore the uncertainties and complexities in the decision making process and the interconnections between natural resources. Both concepts of resilience and livelihood are related to the complexities embedded in the relations between humans and environment (BECK; VILLARROEL WALKER, 2013; MATTHEWS; MCCARTNEY, 2018)

4.2 Subject Categories of the WEF Nexus Literature

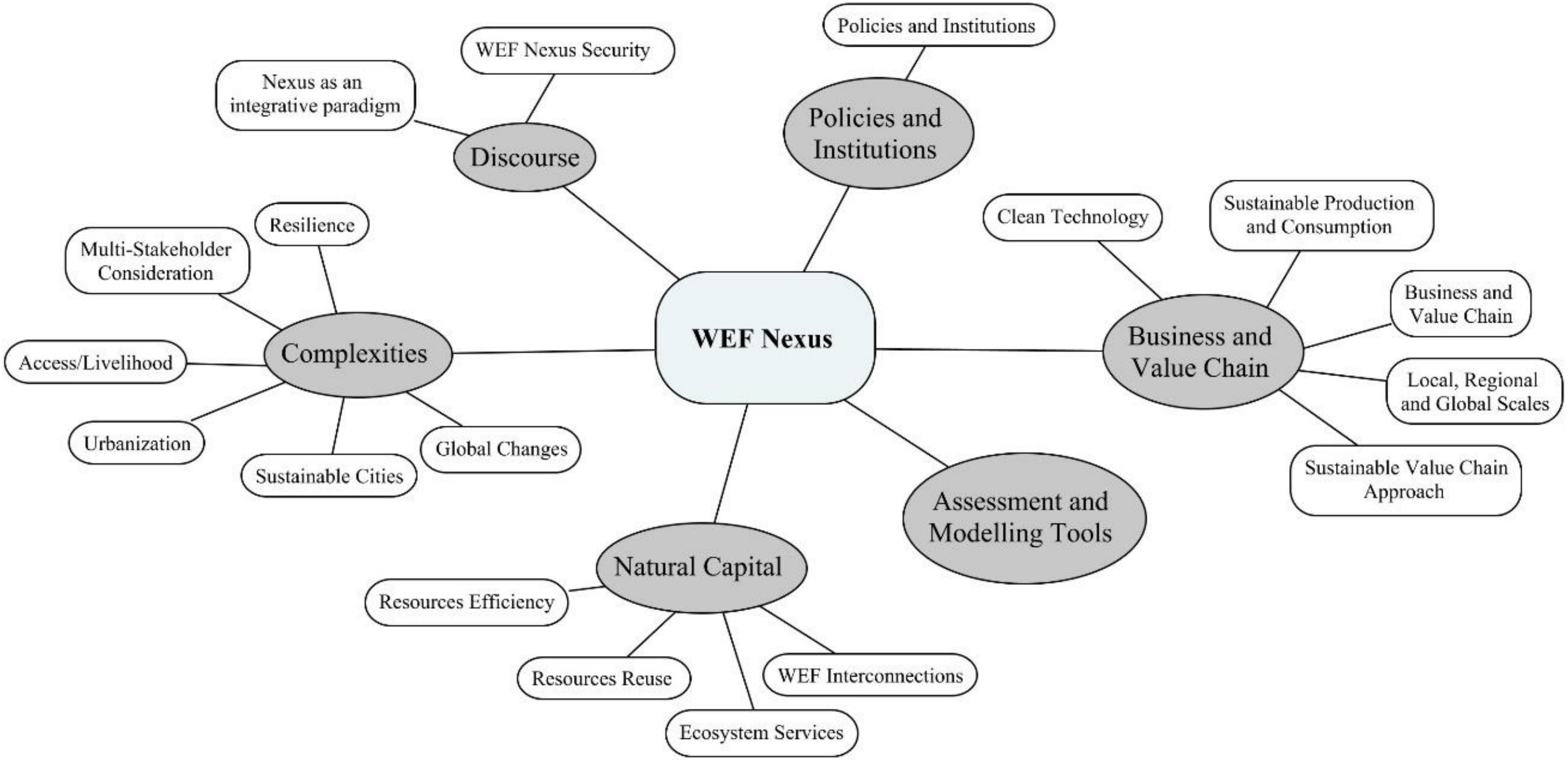
As described in Section 3.1, two coding rounds were performed to enable content analysis of the paper sample. To support the identification of the specific WEF Nexus principles, an overview of the main concepts and constructs involved in the scientific production of Nexus community, using a preliminary thematic synthesis. This in-depth data analysis enabled the identification of certain groups of subjects covered in the articles (first order categories). Thus, we propose six main approaches of this literature: Discourse, Natural Capital, Business and Value Chain, Complexities, Policies and Institutions, Assessment and Modeling Tools (Fig. 6). These categories were further detailed into the second order categories (also represented in Fig. 6). Each category is discussed below.

4.2.1 Discourse

This first order category is composed by the second order categories with papers addressing WEF Nexus security and WEF Nexus as an integrative paradigm. This group of analysis embraces publications that encompass WEF Nexus issues in a more comprehensively way. In this broader sense, it was named based on the definitions of Keskinen et al. (2016) of Nexus perspectives. In the Nexus literature, the perspective of Discourse represents the value level, embodying ethics, science and philosophy about WEF Nexus (KESKINEN et al., 2016). From the sample, 28 articles present Discourse as the main theme of the paper. Some publications examine the relevance of Nexus as an integrative approach (Bazilian et al., 2011; Keairns et al., 2016). Further, publications have addressed the Nexus as a paradigm, discussing its theory (ALLOUCHE; MIDDLETON; GYAWALI, 2015; LECK et al., 2015; SMAJGL; WARD; PLUSCHKE, 2016; WICHELNS, 2017).

Another understanding that can be inferred in this perspective of Nexus is the Water, Energy and Food Security. Although security discussions can be classified in other Nexus perspectives, it is important to highlight this aspect in the Nexus Discourse, since the concept itself claims the security issue, Water, Energy and Food Security Nexus (HOFF, 2011; LEESE; MEISCH, 2015). Security in Nexus can be seen as an evidence of sustainability (BECK; VILLARROEL WALKER, 2013), as well as an outset to analytical and practical actions to resource management (RASUL; SHARMA, 2016; WONG, 2014; WONG; PECORA, 2015). Discussions in this perspective tend to happen at the value level (KESKINEN; VARIS, 2016), providing a foundation to others perspectives and Nexus studies.

Fig. 6 - Main subject categories of the literature of WEF Nexus.



Note - Gray forms refers to the First Order Categories. White Forms refers to the Second Order Categories

4.2.2 Policies and Institutions

Due to the very nature of water, the inclination for riparian countries conflicts is very high in transboundary river basins (KIBAROGLU; GÜRSOY, 2015; YANG et al., 2016). Among other reasons, these conflicts become more likely to occur, given lack of integrated management, appropriated international laws and decision-making process (KIBAROGLU; GÜRSOY, 2015). In the sample, 27 publications addressed Policies and Institutions matters as their core contributions, with a Second Order Category by the same name. Public policies issues in WEF Nexus context are often explored through historical and institutional analysis (KIBAROGLU; GÜRSOY, 2015; SOLIEV; WEGERICH; KAZBEKOV, 2015; VILLAMAYOR-TOMAS et al., 2015). Kibaroglu and Gürsoy (2015) use a historical analysis to explore the Nexus in a transboundary context. Soliev et al. (2015), in a historical and institutional analysis, discuss the cooperation in shared water development by riparian countries. Many publications address international policy in managing resources, especially in transboundary contexts (KIBAROGLU; GÜRSOY, 2015; NHAMO et al., 2018). Hydropower policies, particularly on a transboundary set-up, are also an important research field in the Nexus literature (NASR; NEEF, 2016; SOLIEV; WEGERICH; KAZBEKOV, 2015; YAPIYEV et al., 2017).

4.2.3 Natural Capital: Natural Resources and Environmental Enablers

Another First Order Category perceived from the literature review is the so called "Natural Capital". With four Second Order Categories, a significant amount of articles (n=62) addresses natural resources and environment issues. Some publications address issues as resources interconnections (FINLEY; SEIBER, 2014; PERRONE; HORNBERGER, 2016; VORA et al., 2017). Resource efficiency has to do primarily with recognizing water, energy and food interconnections and have greater outputs, decreasing resources inputs (JARVIE et al., 2015; RINGLER; BHADURI; LAWFORD, 2013; YAO; MARTINEZ-HERNANDEZ; YANG, 2018; ZHANG, 2013). In the same direction, resources reuse is a way of resource efficiency, since it avoids waste production and saves clean and new resources use (AVELLAN; ARDAKANIAN; GREMILLION, 2017; KIBLER et al., 2018; VOULVOULIS, 2015).

Publications aggregated in the Second Order Category of ecosystem services in a WEF Nexus set-up are numerous. For instance, Rasul (2014) discusses the importance of ecosystem services in the management of WEF Nexus in a regional context. Also in a regional approach, Hatfield-Dodds et al. (2015) explores the dichotomy between environmental pressures and economic growth. In addition, ecosystem services can represent options and solutions for managing the WEF Nexus (KARABULUT et al., 2016; STOSCH et al., 2017; VOULVOULIS, 2015), with the trade-offs and wicked problems (GRAHAM; PUEPPKE; UDERBAYEV, 2017; INTRALAWAN et al., 2018; PUEPPKE et al., 2018). In a WEF Nexus perspective, these ecosystem services can affect or be affected by natural and human forces. Two strong elements that influence ecosystem services and water, energy and food resources are land (MIRZABAEV; NKONYA; VON BRAUN, 2015; RINGLER; BHADURI; LAWFORD, 2013; SHARMINA et al., 2016; SICILIANO; RULLI; D'ODORICO, 2017; STOY et al., 2018) and climate (CONWAY et al., 2015; HATFIELD-DODDS et al., 2015; RASUL; SHARMA, 2016; YANG et al., 2016; YAPIYEV et al., 2017; ZHANG X. et al., 2018).

It is also interesting pointing the presence of some natural resources management technologies and phenomena as alternative solutions for managing Nexus: carbon capture (OLSSON et al., 2015; STOY et al., 2018), biochar systems (BELMONTE; BENJAMIN; TAN, 2017), desalination (GENÇER; AGRAWAL, 2018), biorefineries (MIRZABAEV et al., 2015; STOY et al., 2018) and agroecology (DELONGE; BASCHE, 2017).

4.2.4 Business and Value Chain

Albeit the relatively reduced number of articles addressing business and value chain matters (n=15), this thematic category was considered important, in an inductive approach, due the role played by businesses in the pursuit of Sustainable Development (BOLIS; MORIOKA; SZNELWAR, 2014). Some papers map value chains involved in WEF Nexus. Villamayor-Tomas et al. (2015) and White et al. (2018) analyze the virtual value flow of water, energy and food in national (China) and transnational trades. Alternatives to ensuring sustainable production and consumption are also discussed in the papers (DE LAURENTIIS; HUNT; ROGERS, 2016; GARCIA; YOU, 2017).

However, little attention has been paid to economic concepts in a WEF Nexus perspective. New points of view of economy emerge as solution alternatives to WEF Nexus issues, such as green economy (LEESE AND MEISCH, 2015; VLOTMAN AND BALLARD, 2014) and circular economy (BERGENDAHL; SARKIS; TIMKO, 2018; GREEN et al., 2017; KILKIS; KILKIS, 2017; VLOTMAN; BALLARD, 2014). It seems to be an emerging research opportunity the study of the development of a circular economy in order to manage WEF Nexus (BERGENDAHL; SARKIS; TIMKO, 2018; GREEN et al., 2017; KILKIS; KILKIS, 2017). In parallel, some articles focus on the management of supply chain with the purpose of achieving this objective. Alimonti et al. (2017) and Owen et al. (2018) explore the inputs and outputs of water, energy and food over their final products and supply chains. As future work, Belmonte et al. (2017) suggest the development of multi-objectives methods taking into account supply chain metrics. Green et al. (2017) also propose questions for business and researchers in managing the constraints, synergies and impacts of business on WEF Nexus.

Clean technology can transform the environment metabolism, decreasing the use of resources and their waste, and increasing their efficiency (WALKER et al., 2014). The implementation of clean technologies is pointed by some authors as a way to increase system outputs as decreasing natural resources inputs (ARMSTRONG et al., 2018; RINGLER; BHADURI; LAWFORD, 2013; STOY et al., 2018).

4.2.5 Assessment and Modelling and Optimization Tools

A very present and evident feature in Nexus studies is the Assessment and Modelling Tools. The main relevant point in these studies is the claim of the need of integrative approaches when managing Nexus (BAZILIAN et al., 2011). Literature reinforces the transition from siloed thinking to integrated approaches (KEAIRNS; DARTON; IRABIEN, 2016). For that, integrative assessment tools have been proposed in literature (DAHER; MOHTAR, 2015; SCHLÖR; HAKE; VENGHAUS, 2018; VAN VUUREN et al., 2015). Other approach is the exploration and measurement of dynamic links between water, energy, food (KESKINEN et al., 2015; OZTURK, 2015). Albrecht et al. (2018) and Endo et al. (2015) are reviews of Nexus assessments presented in Literature. Publications use different focus assessment parameters for the systems, based on a Nexus framework (MAYOR et al., 2015; PASQUAL et al., 2018; SHRESTHA et al., 2015; YAN et al., 2018).

Furthermore, publications have intended to formulate a model for a Nexus approach. Garcia and You (2016; 2017) and Hang et al. (2016; 2017) address the design of integrated systems as a way to optimize the synergies and mitigate the tradeoffs of WEF interactions. Other papers report multi-objective optimization results

(DHAUBANJAR; DAVIDSEN; BAUER-GOTTWEIN, 2017; KAN et al., 2018; UEN et al., 2018).

4.2.6 Complexities

Managing WEF Nexus is, in fact, more complex than just increase resources efficiency. The complexity of WEF Nexus is understood by the intersection of the broad scope of the “WEF Nexus Thinking” and systems (HARWOOD, 2018; HATFIELD-DODDS et al., 2015; MICKELSON; TSVANKIN, 2018) and its cross-sectorial interactions and implications. In the sample, 36 papers were grouped in this category, albeit most of papers address in some way aspects of complexities in managing the WEF Nexus.

Concerning WEF Nexus Complexities, Biggs et al. (2015) argue that ensuring livelihood and access to natural resources are key ways to achieving sustainable development. Managing systems under a WEF Nexus perspective would be, therefore, a plausible approach to achieve more sustainable societies (BIGGS et al., 2015; KESKINEN et al., 2015; NHAMO et al., 2018). It is also critical, also, to embrace a multi-stakeholder consideration when managing WEF Nexus systems (HALBE et al., 2015; MARTINEZ; BLANCO; CASTRO-CAMPOS, 2018; PORTNEY et al., 2018). A broader and more inclusive debate can links public, private and civil-society sector to answer sustainability challenges (SCHMIDT; MATTHEWS, 2018).

Considering particularities of spatial scale is essential for an efficient WEF Nexus management (BIJL et al., 2018). The potentialities, hazards and interconnections between WEF Nexus nodes change drastically when local, regional and global scales are taken into account (BIJL et al., 2018; GRANIT et al., 2012; SUŠNIK, 2018)

Other references had an specific approach on the role played by the WEF Nexus in the development of Sustainable Cities (TOPI; ESPOSTO; MARINI GOVIGLI, 2016; WALKER et al., 2014; ZIMMERMAN; ZHU; DIMITRI, 2018). In addition to deal with resources interconnections, Sustainable Cities has to do with facing the challenge of growing urbanization and limited resources as a sustainable option for meeting these questions (BECK; VILLARROEL WALKER, 2013; TIEN, 2018).

The complexity involving WEF Nexus revolves around global changes (BENSON; GAIN; ROUILLARD, 2015; RASUL; SHARMA, 2016; ZHANG X. et al., 2018). Natural disasters, climate, political, institutional and economic changes can jeopardize natural resources. In this sense, management approaches need to consider a WEF Nexus perspective, in order to strengthen environment resilience from which the environment can recover and product (specially ecosystem services) in the face of a major disturbance (DE GRENADE et al., 2016; SCHMIDT; MATTHEWS, 2018; UDDAMERI; REIBLE, 2018).

4.3 Delimitation of WEF Nexus Principles

The previous results presented in Section 4.1 and 4.2 were useful to support building gradually an in-depth understanding of the WEF Nexus literature. These more general literature analyses were relevant to provide a more specific contribution, which is to better delimit the concept of WEF Nexus by proposing associated principles. The identified patterns can be defined as values and features that serve as a guide for evaluating and managing a system in a WEF Nexus Paradigm. In this research, this patterns were called by the concept of WEF Nexus Principles. Some of WEF Nexus Principles are listed in Table 7. This is not an exhaustive list, but the opposite: it can be seen as a guide to deal with sustainability through a WEF Nexus lens.

WEF Nexus Principles contemplate aspects from the very nature of the construct, from a Water, Energy and Food Security perspective. Elements of environment natural capital, as resources efficiency, resources reuse and ecosystem services also appear as frameworks for managing WEF Nexus nodes. As mentioned before, clean technologies are an important driver to transformations that meet Sustainable Goals (RINGLER; BHADURI; LAWFORD, 2013).

Some issues regarding Complexities around the WEF Nexus were also considered, as the guarantee of resources access and livelihood, a multi stakeholder consideration, the assurance and development of local, regional and global scales, the promotion of sustainable cities and resilience, as a way of environmental resistance.

In the next section, case studies technologies are analyzed in the light of these WEF Nexus Principles, in order to identify technologies' alignment to the WEF Nexus Thinking.

Table 7 – WEF Nexus Principles

Principle	Description	References
Water, Energy and Food Security	Access to clean, reliable and affordable water, energy and food for survival (HOFF, 2011).	Benson et al. (2015); Biba (2016); De Laurentiis et al. (2016); Finley and Seiber (2014); Grafton et al. (2016); Lawford et al. (2013); Leese and Meisch (2015); Olsson (2013); Ozturk (2017); Rasul (2014); Verhoeven (2013); Wong and Pecora (2015); Zhang (2013); Gain et al. (2015); Rasul and Sharma (2016); Abdullaev and Rakhmatullaev (2016); Giupponi and Gain (2017); Zhao et al. (2018).
Resources Efficiency	Maximization of resource use, reducing waste, in order to produce more with less.	Bazilian et al. (2011); Lawford et al. (2013); Zhang (2013); Jarvie et al. (2015); Jobbins et al. (2015); Mirzabaev et al. (2015a); Shrestha et al. (2015); Amos et al. (2016); Damerau et al. (2016); Hang et al. (2016); Li et al. (2016); Smidt et al. (2016); Walsh et al. (2016); Haie (2016); Shifflett et al. (2016); Topi et al. (2016); Hang et al. (2017); El-Gafy (2017); Mohtar and Daher (2017); Pringle et al. (2017); Martinez-Hernandez and Samsatli (2017); Schwanitz et al. (2017); Kibler et al. (2018); Yao et al. (2018); Gençer and Agrawal (2018); Harwood (2018).
Resources Reuse	Reutilization of resources for another purpose after their use.	King and Jaafar (2015); Voulvoulis (2015); Garcia and You (2017); Avellan et al. (2017); Miller-Robbie et al. (2017); Martinez-Hernandez and Samsatli (2017); Helmstedt et al. (2018); Kibler et al. (2018); Lin et al. (2018); Pasqual et al. (2018).
Access/livelihood	The means of securing the needs for maintain life.	Allouche et al. (2015); Biggs et al. (2015); Keskinen et al. (2015); Ozturk (2017); Guta et al. (2017); Nhamo et al. (2018).
Multi-Stakeholder Consideration	Decision making and planning from the perspective of multiple stakeholders.	Halbe et al. (2015); Keskinen et al. (2015); Mirzabaev et al. (2015a); Smajgl et al. (2016); H. F. Khan et al. (2017); White et al. (2017); Helmstedt et al. (2018); Kibler et al., (2018); Sušnik et al. (2018); Wyrwoll et al. (2018); Avellán et al. (2018); Bullock and Bowman (2018); Harwood (2018); Martinez et al. (2018); Portney et al. (2018).
Ecosystem Services	The benefits extracted from a well-functioning natural ecosystems.	Hatfield-Dodds et al. (2015); Rasul (2014); Hack (2015); Mirzabaev et al. (2015b); Vanham (2016); Voulvoulis (2015); Karabulut et al. (2016); Irabien and Darton (2016); Graham et al. (2017); Stosch et al. (2017); Uddameri and Reible (2018); Intralawan et al. (2018); Pueppke et al. (2018); Avellán et al. (2018).
Local, Regional and Global Scales	The viability of production security in local, regional and global scales.	Granit et al. (2012); Garcia and You (2016); Hang et al. (2016); Jalilov et al. (2016); Irabien and Darton (2016); Giupponi and Gain (2017); Hang et al. (2017); Hussien et al. (2017); Artioli et al. (2017); Siciliano et al. (2017); Stoy et al. (2018); Karan et al. (2018); Nhamo et al. (2018); Sušnik (2018).
Sustainable Cities	Cities planned and managed with the consideration of their social, environmental and economic impacts	Walker et al. (2014); Topi et al. (2016); Miller-Robbie et al. (2017); Ramaswami et al. (2017); Artioli et al. (2017); Gondhalekar and Ramsauer (2017); Schlör et al. (2018b); Zimmerman et al. (2018); Tien (2018).
Clean Technology	Technologies with reduced or none negative impact on environment	Ringler; Bhaduri; Lawford (2013);Walker et al. (2014); Mirzabaev et al. (2015a); Olsson et al. (2015); Halbe et al. (2015); Walsh et al. (2016); Gouma et al. (2016); Closas and Rap (2017); Loik et al. (2017); Pringle et al. (2017); Verstraete and De Vrieze (2017); Cai et al. (2018); Stoy et al. (2018); Armstrong et al. (2018).
Resilience	The capacity of systems to maintain same function when suffering significant disturbance (BECK; VILLARROEL WALKER, 2013).	Beck; Villarroel Walker (2013); De Grenade et al. (2016); Yang and Wi (2018); Matthews and Mccartney (2018); Schmidt and Matthews (2018); Tien (2018); Uddameri and Reible (2018)

5. RESULTS FROM THE CASE STUDIES

In this section, results from the case studies are discussed. Subsection 5.1 aims to meet the research specific objective #2 by analyzing case studies technologies adjustments to the WEF Nexus Principles identified in Table 7. Next, subsection 5.2 answers research specific objective #3 by analyzing the impact of technologies implemented in case studies business models.

5.1 Analysis of Technologies from WEF Nexus Principles Perspective

This research was developed analyzing seven technologies innovation implementations in four different firms in the agribusiness. This chapter is divided in two main parts: Technology Analysis (Section 5.1) and Impact of Technologies on Business Model Elements (Section 5.2). First, the technologies implemented will be analyzed considering WEF Nexus Principles (Table 7). The second part will examine what may have changed in the case firms' business models with technologies implementations. Now, a summary of the companies studied is presented.

Firm A is the largest mango producer and exporter in Brazil, located in the Northeast of the country, since 1987. Its farms are located in São Francisco Valley. This firm is composed by eight different farms placed in the states of Pernambuco and Bahia. Firm A has a strong appeal to social responsibility, with an employee management system called Basic Management Units, results driven, which allows continuous qualification and evaluations of staff members. Also, Firm A has a project of an elementary school in the region, that serves 270 students up to the seventh grade. Only 20% of the students are children of employee, because the goal of the school is to reach the whole local community.

Firm B is a fruit producer, and fruit and vegetables seller and distributor since 1993. It is located in Paraíba, Northeast Brazil. Besides producing, selling and exporting pineapple and papaya, Firm B stores and distributes a catalog of dozens of varieties of fruits and vegetables. There are distributions centers spread across five states in the Northeast Brazil (Bahia, Pernambuco, Paraíba, Rio Grande do Norte, Ceará) and about 3000 direct and indirect employees.

Firm C is a fruit and vegetables producer and distributor located in Minas Gerais, Southeast Brazil. Is has been on marketing since 1999 and employs about 230 people, direct and indirectly. Besides producing strawberry and broccoli, Firm C distributes lettuce and cauliflower.

Firm D is a rural producer of organic vegetables and animals, located in Paraíba, Northeast Brazil. It follows the precepts of agroecology, with integrated biosystems for animal and vegetables farming (vegetables, pig and fish farming), observing social and environmental sustainable principles.

For this part of research, the different technologies adopted by the firms that interfered in the synergy and tradeoffs between water, energy and food were considered as units of analysis for the present case studies (Table 3). Following, these technologies are briefly described, considering the WEF Nexus Principles (Table 8) **Erro! Fonte de referência não encontrada.** summarizes the relationship between the effects of the technology analyzed over the WEF Nexus Principles (Table 7) described in the following paragraphs.

Table 8 - Technologies x WEF Nexus Principles

	A1	B1	C1	AB1	A2	C2	D1
Technology	**Dendrometric evaluation system as an indicator for plantation irrigation management**	**Micro Splinker Irrigation;**	**Solar based energy for irrigation**	**Packing house water reuse**	**Sewage treatment**	**Semi Hydroponics strawberry cultivation**	**Use of microalgae biomass in an integrate biosystem**
Water, Energy and Food Security	WEF	WF	WEF	WF	WF	WF	WEF
Resources Efficiency	✓	✓	✓	✓	✓	✓	✓
Resources Reuse				✓	✓		✓
Access/Livelihood							✓
Multi-Stakeholder Consideration	✓					✓	✓
Ecosystem Services			✓				
Local, Regional and Global Scales							✓
Sustainable Cities				✓	✓		✓
Clean Technology			✓	✓	✓	✓	✓
Resilience			✓	✓	✓	✓	✓

Note 1 - ✓- Direct Relationship
Note 2 - It was considered that all the analyzed technologies had a positive impact on Food Security, since all case firm had food production as final activity.
Note 3 – W – Water Related / E – Energy Related / WE – Water and Energy Related

5.1.1 A1 - Dendrometric Evaluation System as an Indicator for Plantation Irrigation Management

The first technology analyzed was A1, which is dendrometric evaluation system as an indicator for plantation irrigation management. This technology was implemented by firm A and takes into account a sample of three trees per area. Dendrometric evaluation consists of an assessment of the need for irrigation from tree stem diameter verification. During the day, the tree diameter can vary about 8 millimeters, depending on its hydration level. This variation can indicate if the tree needs more or less irrigation. The information about stem diameter is transformed into a color system that suggests the right amount of water that should be used in the irrigation process.

A more precise disposal of water for irrigation can guarantee about 25% of water saving. Furthermore, as the irrigation system is promoted through electric pumping, likewise there was a significant reduction in the use of energy, according as the amount of food produced was not affected, increasing the system resource efficiency.

Dendrometric evaluation system adoption can ensure local water saving, increasing quality water resources availability and a reduction in the demand for fossil electric energy. This represents a strengthening in the Water, Energy and Food Security concept, since it stands for availability of reliable and clean water, food and energy (HOFF, 2011).

After technology A1 implementation there was a change in work quality. Before the remote assessment of tree irrigation need, the presence of a specific worker in the field was necessary to check soil moisture in each area of the field. Currently, most of the work of irrigation need monitoring is made remotely. When asked about work conditions after A1 implementation, the respondent indicated that the technology did not cause unemployment of former existing work stations, but rather an improvement in working conditions and employee qualification.

No significant impacts of the mentioned technology were noticed over the Nexus principles of Resources Reuse, Access and Livelihood, Ecosystem services, Local, Regional and Global Scales, Sustainable Cities, Clean Technology and Resilience.

5.1.2 B1 - Micro Splinker Irrigation

Micro splinker is a system that considers located irrigation through microparticles of water emitted at high pressure by microsplinker emitters, and it is a popular technology in agriculture. It is an indicated irrigation system for high temperature climates, because its particles help in temperature reduction. Besides, it is possible to expel nutrients for the plant as well.

Technology B1 adoption can ensure an increase of Water, Energy and Food Security, since it promotes water saving and consequently providing more quality water resources available. There is also an increase in resources efficiency, given that a located irrigation promotes water and energy saving, preventing from unnecessary disposal of energy and water.

No significant impacts of the mentioned technology were noticed over the Nexus principles of Resources Reuse, Access and Livelihood, Multi-Stakeholder Consideration, Ecosystem services, Local, Regional and Global Scales, Sustainable Cities, Clean Technology and Resilience.

5.1.3 C1 – Solar Based Energy for Irrigation

The system of photovoltaic solar panels was implemented in the firm C in 2019, and converts solar energy into electric energy. 100% of the energy used in irrigation pumping on Firm C comes from photovoltaic energy. In this food production process in firm C there is no use of fossil energy.

Photovoltaic energy production for irrigation uses solar energy, which is a renewable energy, as energy source for irrigation. Therefore, it increases energy security by providing clean energy for food production. Also, there is an increase of resources efficiency, considering that no fossil energy is used in the process, increasing energy availability.

There is an improvement in the use of ecosystem services, since photovoltaic panels can convert solar energy into electric energy for irrigation.

C1 presents itself as a clean technology, as it uses renewable energy (solar energy) as main source of energy. Further, it enables a stronger system resilience, with less production dependence on conventional energy to have the same performance. No significant impacts of the mentioned technology were noticed over the Nexus principles of Resources Reuse, Access and Livelihood, Multi-Stakeholder Consideration, Local, Regional and Global Scales and Sustainable Cities.

5.1.4 AB1 – Packing House Water Reuse

Packing house is a facility where the fruit can be received from field/provider, processed, classified, packed and forwarded for storage and shipping. In this stage of food chain, water is used in several fruit washing lines, sanitizing treatments and quality tests. The water used in some of packing house processes in firms A and B are treated and reused in secondary processes or irrigation.

Water reuse in some processes of packing house reduces clean water consumption, increasing water security. Furthermore, there is an improvement of resource efficiency and water reuse, since there is water saving without compromising the quality and amount of food produced.

The reuse of water in firms A and B is aligned with the concept of Sustainable Cities and Resilience, basically duo two factors. First, part of effluents that formerly were disposed in river sheets and sewage are now reused or dumped to irrigation. There is less river and soil contamination and less water waste. Second, despite the reduction in water disposal, the volume of food processed and produced has not changed, given that part of the water is reused. The filtering and water treatment system for reuse is a clean technology insofar as take water as a renewable source, increasing system efficiency using less resources.

No significant impacts of the mentioned technology were noticed over the Nexus principles of Access and Livelihood, Multi-Stakeholder Consideration, Ecosystem Services and Local, Regional and Global Scales.

5.1.5 A2 - Sewage Treatment

All the sewage produced in the process of firm A is treated and reused in garden cultivation. Thereby, there is no more river contamination with sewage waste, in addition to less final waste generated.

With the sewage treatment, there is less soil and river water contamination with sewage waste; there is also an increase in quality water resources available, increasing Water Security. The water treated is used in garden cultivation; so there is a water saving and reuse.

Firm A is the only company in the region that does not dump sewage waste in the river, promoting sustainability for the region. Also, A2 appears as a clean technology, as sewage treatment technology fosters less soil and water pollution, besides not polluting the river. Furthermore, A2 strengthens production resilience, because there is no river contamination, despite the waste production. Further, in case of less water disposal, it would cause less impact in production, given part of water is reused.

No significant impacts of the mentioned technology were noticed over the Nexus principles of Access and Livelihood, Multi-Stakeholder Consideration, Ecosystem Services and Local, Regional and Global Scales.

5.1.6 C2 - Semi Hydroponics Strawberry Cultivation

Firm C implemented semi hydroponics strawberry cultivation in 2009. The semi hydroponics system consists in strawberry culture, in an inert substrate, in greenhouses. Irrigation water is pumped through solar energy, coming from solar panels. This technology enables the use of less water and pesticides in cultivation.

Technology C2 is a Water, Energy and Food Security and Resource Efficiency driver, since it uses less water, food and soil contamination. Further, no fossil energy is used in the direct process.

Considering different stakeholders, C2 implementation had a direct impact on work conditions. In the conventional system, workers had vision problems, due strawberry white tunnels and spine problems. Besides, the work routine was conditioned to climate conditions. In semi-hydroponics system, the work is developed in greenhouses, which has a better light and climate control. In addition, it allows a better posture, because the strawberry is now farmed on countertops.

C2 is a clean technology that provides water saving and less chemical pesticides use in process. Once the fruit is on an inert and controlled substrate, in a greenhouse, there is less contamination and contact with pests, so less pesticides are used. Consequently, in addition to less environmental impact, the fruit harvested is healthier.

C2 implementation increases system resilience considering that the same amount of food is cultivated and harvested with less water, pesticides and conventional energy. Further, food production would not be harmed in case of severe climate changes or soil contamination, for example.

No significant impacts of the mentioned technology were noticed over the Nexus principles of Resources Reuse, Access and Livelihood, Ecosystem Services, Ecosystem Services and Local, Regional and Global Scales and Sustainable Cities.

5.1.6 D1 – Microalgae Biomass Production for Integration in Organic Food Farming Integrated Biosystems

In 2017 Firm D was contemplated in a Call for Sustainable Projects with the aim of strengthening the concept of Water, Energy and Food Security, from WEF Nexus. The Call is sponsored and monitored by the National Council for Scientific and Technological Development (CNPq – Conselho Nacional para Desenvolvimento Técnico e Científico).

Technology D1 consists of the integration of a technology for microalgae biomass production in an integrated biosystem, in a small production, with agroecological concerns. The technology is basically composed by tanks for biomass production and a biodigester. The biosystem is composed by two parts: one involving organic and fish farming, and the other involving a biodigester, organic and pig farming.

In the first part of the biosystem, the main purpose for microalgae biomass production is to the serve as fish feed. Then, the effluents of microalgae biomass are used in the organic farming irrigation, and the clean water treated is reused in the tanks for more microalgae biomass production.

The second part of the biosystem starts with the biomass serving as protein supplementation for pig farming. Animal waste is taken to the biodigester, where three by-products come from. First, the gas from animal waste is washed, and biogas (methane) is produced. This biogas will be used as energy source in production. The second by-product is sludge treated for fertilizer, that will be disposed on organic vegetable farming. Lastly, biodigester effluents are used in microalgae farming. In total, the water in system is reused three times. With D1 implementation, there was release of productive area. In the former system, the producer cultivated other vegetables that served exclusively as animal feed.

D1 technology strengthens Water, Energy and Food Security. Increase on water security because the water used in the bioreactor is reused three times, increasing availability of quality and clean water. D1 enables increase on energy security because of the production of clean energy (biogas, methane) from effluents. Besides coming from effluents, this methane produced has higher quality than the gas used before D1 implementation. D1 enables strengthening of food security because there is an increase of productive land, food production cost reduction and a rise on food production.

D1 implementation represented resource efficiency, since it enabled water consumption reduction, water reuse, effluent reuse and higher quality energy generation from effluent (biogas). Although there is a primary increase in energy use, with pumping for material circulation, the energetic balance of the system is positive, given the high quality biogas produced from effluents.

D1 meets the principle of Resource Reuse when recycles animal, biodigester and bioreactor effluents and water. Besides, the contribution of D1 for Sustainable Cities is twofold. First, there is less waste disposal and an increase on soil quality (water used in irrigation from biomass effluents is nutrient-rich). Second, this technology is accessible for other stakeholders who want to implement it.

Here, the idea of Social Technology appears as a participatory approach, with accessible and low cost options of technology, that can take place to integrate local systems, and coexist with local community (ALCÓCER et al., 2019; MACHADO; LA ROVERE, 2017). The access to Water, Energy and Food was enhanced. As D1 has the premise of being a Social Technology, following agroecology principles, it opens the possibility of access to the technology by other producers and agricultural communities. On the same line, D1 has a multi-stakeholder consideration alignment, given that its adoption might stimulate the increase of agroecological production and consumption by local community, besides providing an improvement of quality of life. Further, this technology adherence can promote a stimulus of a greater local, regional and even global scale of agroecological production.

D1 is a clean technology that reduces waste disposal, reuses water and generates energy (methane, biogas). It enhances production resilience. D1 implementation promote productive land use reduction, with the same or increased amount of food produced. Yet, the production would be little harmed in case of less water security, land issues or others disturbances. No significant impacts of the mentioned technology were noticed over the Nexus principle of Ecosystem Services.

5.2 Impact of Technologies on Business Models from Sustainability Perspective

In order to meet the third research objective, which is *"to analyze how the implementation of new technologies affect business models, in terms of Value Proposition, Value Creation and Delivery System and Value Capture",* the business models (case firms) were considered as the research analysis units. It was necessary because more than one studied technology can be embedded in the same firm. This section is composed by three sub-sections: Value Proposition, Value Creation and Delivery System, Value Capture.

5.2.1 Value Proposition

Throughout the years, Firms A, B, C and D had adopted some actions that contemplate sustainable principles of the triple bottom line. When it comes to the analyzed technologies, their implementation helped to meet some Sustainable Development Goals that are in the core of the companies, as clean water and sanitization, decent work, life and land. However, these actions did not represent a direct influence on product value proposition.

5.2.2 Value Creation and Delivery System

In an attempt of considering the whole idea of a firm Value Creation and Delivery System, this Business Model element will be analyzed according to specific areas and activities of the organization (MORIOKA; BOLIS; CARVALHO, 2018): human resources, operations and supply chain & logistics. Table 9 provides an overview of the main changes in the Value Creation and Delivery System perceived in the analyzed firms.

Other transformations in value creation may have occurred, but not evidenced in the interviews.

In the area of Human Resources, significant changes were perceived specially in Firms A and C. Particularly in Firm A, it was noticed an increase in the demand for qualification in the same work routine. The respondent from firm A commented that is good for the firm that people specialize for new activities in the company. In firm C there was observed an improvement in the life quality of workers, in terms of ergonomics: less back and sight problems. Further, after technology implementation, there was a decrease in manpower demand: with the implementation of technologies for semi-hydroponics cultivation, Firm C managed to double production with the same amount of employees.

The most evident changes that occurred in all business model operations has to do with energy and water saving. As all technology implementations sought primarily increase resources efficiency (water and energy, for food production, essentially), it was predictable that a reduction in water and energy demand for production would occur. In firms C and D, technologies implementation made possible a release of productive land for other uses or an increase in production. With technologies implementation, particularly on Firms A and C, it was observed a reduction on climate conditions dependence for work routines. First, because workers, in Firm C, are protected from sun and rain, due the protection of the greenhouse. Second, remote irrigation monitoring reduced the need of worker constant presence in field, monitoring plant irrigation demand (Firm A).

In Firm D was noticed a change in the internal supply chain, with a change in inputs for production. Before D1 implementation, part of productive land was used to peanut cultivation, that served as feed for pig farming. After D1 implementation, microalgae biomass was used as protein supplement in pig feed, releasing productive area for other users (value capture).

Table 9 – Changes in Value Creation and Delivery System

Practices/ Capabilities/ Resources	VCDS Change	Statements
Human Resources	Workforce qualification	"These people are specializing and we have people. […] But our goal is not to use technology to unemploy, because our labor is not expensive." (Firm A)
	Improvement in the life quality of workers.	"The employee's advantage is that, because he works standing up, in this bench system, he has no back problem. We reduced 70% of the staff's back pain complaints. […] Because the white light made people lose their sight power. And in the semi-hydroponic system, people work in the greenhouse, so there is no such problem." (Firm C)
	Decrease in manpower demand	"[…] I will spend an extra employee, because I have 100,000 plants, 10,000 plants per person, 10 people. However, I have, as I told you earlier, almost twice as much, more than twice the plant population. So it's a double gain in labor, if you analyze it." (Firm C)
Operations	Less Water Use	"The idea is to work with the limit between green and yellow lights, which is the most economical limit, and to put what the plant needs in terms of water, and saving about 25% of the water. So we are adopting this system in order to meet the plant well reducing water consumption significantly. " (Firm A). "So I basically have more than twice the population and spend less water. Because the water goes only to the plant, there is no waste. Speaking of water consumption, this is one of the advantages of the semi-hydroponic system." (Firm C). "We have water reuse. The same water that he would use for irrigation, it will only take a while to go to irrigation, because I need to produce the microalgae." (Firm D) "It [water] keeps dropping only where the plant is, so it will only get wet around the root of the plant." (Firm B)
	Positive Energetic Balance	"Yes, because the water is directly connected to the water pumping. You have less pumps being used, so there will be less energy consumption to pump that water. Water consumption and energy consumption are directly proportional." (Firm A) "But our electricity is clean, as I said, it is photovoltaic. So the irrigation expenditure is zero. We use electricity, which is clean energy, so it's fine. So we saved, exchanged fossil energy for clean energy." (Firm C) "And the issue related to energy comes into the same concept: his energy expenditure could increase if I had been analyzing the system only from the perspective of the need for a pump to circulate water. However, if I look at the whole context, the energy I am spending on that pump, makes up for what it is producing from methane, from biogas. So I have a positive energy balance, it will start generating energy, and it will have a positive balance in relation to food production." (Firm D)
	Increase on productive land	"Semi-Hydroponic Strawberry, in one hectare, we can plant one hundred thousand (100,000) plants. And the same hectare, if we are going to plant in the conventional system, only forty-five thousand (45,000) plants can fit." (Firm C) "So the intention is to replace this peanut with microalgae biomass, which has the highest percentage of vegetable protein. So theoretically we are releasing his productive area for him to produce these things. He does not need to produce peanuts and harvest the peanuts to feed the pigs." (Firm D)

	Change in work routines	"In the conventional system, if it rained, the staff cannot work. In the semi hydroponic system, because it is a greenhouse, people can work under the sun and rain. Because it's inside the greenhouse, so it's easier; don't have the problem of not working. […] In the conventional system, if it rained, the staff cannot work. In the semi hydroponic system, because it is a greenhouse, people can work under the sun and rain. Because it's inside the greenhouse, so it's easier; don't have the problem of not working" (Firm C). "[…] We still use this as a reference, but it is gradually to be more information for this monitoring, for this satellite system. And it avoids that the person needs to go there in the field to really see how the irrigation situation is." (Firm A).
Supply Chain and Logistics	By-Products change	"So the intention is to replace this peanut with microalgae biomass, which has the highest percentage of vegetable protein. So theoretically we are releasing his productive area for him to produce these things. He does not need to produce peanuts and harvest the peanuts to feed the pigs." (Firm D)

Other aspects of technology implementation may have occurred, but in this research evidences did not indicate significant changes observed on the Value Creation and Delivery System of Marketing and Sales, Innovation/R&D, Organizational Culture and Corporate Governance.

5.2.3 Value Capture

With the aim of mapping evidences from interviews' respondents that identify direct and cascaded value captured by Firms' stakeholders, Table 10 shows the main value captured aspects observed, with the statements, divided by organizations' stakeholders.

The first stakeholders that receive value from the innovation implanted are the shareholders/investors/owners. When it comes to financial gain due cost reduction, three driver aspects can be highlighted: energy and water use reduction, less waste disposal and reduction on hand labor. Technologies A1, B1, C1, C2 and D1, for example, boosted financial value captured from water and energy cost reduction. Meanwhile, technology C2 provided cost reduction related to labor. Indirect financial value is also perceived. Increasingly, customers have sought to more sustainability companies and products driven, and clean technologies and processes innovation strengthens these ideas. Also, innovation in technologies could increase the area of productive land, releasing more space for production.

The research brings evidence also of value captured by workers. For instance, technologies A1 and B1, and technology C2 enabled workers to capture value in term of improved qualification and improved quality of life, respectively. Customers and society are also benefited, by having access to more sustainable fruits and products, with no agrochemical products and more sustainable water and carbon footprints.

Research evidences also indicate cascaded value captured. Particularly to Firm D, because D1 is a Social Technology, which is freely approachable, other stakeholders can have access and benefit from technology, as suppliers, partners, society in general and competitors. Referring to these, access to the technology D1, could promote, for instance, in addition to fair competition, a growth in agroecological production and consumption.

Results indicate that the natural environment itself captures direct and cascaded values. Technologies innovation aligned with WEF Nexus Principles foster less environmental impact and resources efficiency and reuse. Further, some processes can, as technology D1, increase environment quality besides reducing impacts, as enriching soil quality through nutrient-rich effluents disposal for irrigation.

Table 10 – Changes in Value Capture

Stakeholder	Value Captured	Statements
Shareholders / Investors / Owners	Financial value capture due investments in sustainability.	“Today, more and more customers from abroad demand this responsibility from the company, and they pay for it. […] it [international certifications and investments in sustainability] helps us to sell more than competitors in the same period, for the customer to know that behind [our] production there is the whole social, environmental process.” (Firm A)
	Cost Reduction related to water use and waste reduction	"The idea is to work with the limit between green and yellow lights, which is the most economical limit, and to put what the plant needs in terms of water, and saving about 25% of the water. So we are adopting this system in order to meet the plant well reducing water consumption significantly. " (Firm A). “It [water] keeps dropping only where the plant is, so it will only get wet around the root of the plant.” (Firm B) “So I basically have more than twice the population and spend less water. Because the water goes only to the plant, there is no waste. Speaking of water consumption, this is one of the advantages of the semi-hydroponic system.” (Firm C) “We have water reuse. The same water that he would use for irrigation, it will only take a while to go to irrigation, because I need to produce the microalgae.” (Firm D)
	Cost Reduction related to energy use reduction	“But our electricity is clean, as I said, it is photovoltaic. So the irrigation expense is zero. We use electric energy, which is clean energy, so it’s easy. So we saved, exchanged fossil energy for clean energy.” (Firm C) “And the issue related to energy comes into the same concept: his energy expenditure could increase if I had been analyzing the system only from the perspective of the need for a pump to circulate water. However, if I look at the whole context, the energy I am spending on that pump, makes up for what it is producing from methane, from biogas. So I have a positive energy balance, it will start generating energy, and it will have a positive balance in relation to food production.” (Firm D)
	Increase on productive land	“Semi-Hydroponic Strawberry, in one hectare, we can plant one hundred thousand (100,000) plants. And the same hectare, if we are going to plant in the conventional system, only forty-five thousand (45,000) plants can fit.” (Firm C) “So the intention is to replace this peanut with microalgae biomass, which has the highest percentage of vegetable protein. So theoretically we are releasing his productive area for him to produce these things. He does not need to produce peanuts and harvest the peanuts to feed the pigs.” (Firm D)
	Cost reduction related to labor reduction	“[…] I will spend an extra employee, because I have 100,000 plants, 10,000 plants per person, 10 people. However, I have, as I told you earlier, almost twice as much, more than twice the plant population. So it's a double gain in labor, if you analyze it.” (Firm C)

Employees	Staff qualification.	"These people are specializing and we have people." (Firm A) "Everyone wins. You see the staff, they are more aware of the issue of waste, the issue of hygiene, there is a lot of training." (Firm B)
	Improvement in the quality of life of the worker.	"We reduced 70% of the staff's back pain complaint. […] Because the white light made people lose their sight power. And in the semi-hydroponic system, people work in the greenhouse, so there is no such problem." (Firm C)
Customers	More sustainable fruits, with no agrochemical products	"And in the semi hydroponic system, we have a 95% gain in the result, but detail: we use biological product." (Firm C) "But just the fact that they produce according to the concepts of agroecology is already a great incentive for local consumers, to purchase more products" (Firm D)
Suppliers/Partners	Technology Access (Social Technology)	"[...] as we are trying to get closer to the concept of social technology, it is open to society, to any producer who wants to replicate the project." (Firm D)
Society	More sustainable fruits, with no agrochemical products	"And in the semi hydroponic system, we have a 95% gain in the result, but detail: we use biological product." (Firm C) "But just the fact that they produce according to the concepts of agroecology is already a great incentive for local consumers, to purchase more products" (Firm D)
	Technology Access (Social Technology)	"[...] as we are trying to get closer to the concept of social technology, it is open to society, to any producer who wants to replicate the project." (Firm D)
Environment	Less environmental impact, resources efficiency and reuse, clean technology	"And in the semi hydroponic system, we have a 95% gain in the result, but detail: we use biological product." (Firm C) "[…] such as improving the quality of life (I'm impacting society), the environment, because I'm managing to make them produce more in the area they occupy, then the same area, right ?! Or favor the expansion of this type of sustainable agriculture. And financial gain is inside." (Firm D)
	Increase in soil quality	"[…] and the rejection of this microalgae biomass production he can still use to irrigate and improve the quality of the soil." (Firm D)
Competitors	Fair Competition Stimulation	"It would help the rural producer in the competitor issue. He knows he has a need in the market for organic products consumption." (Firm D)

6. DISCUSSIONS

This study set out with the aim of analyzing the impact of implementation of new technologies aligned with WEF Nexus Thinking on Business Models. Interviews on four distinct companies were conducted, in order to analyze the alignment of seven different technologies with WEF Nexus Principles (Table 7) and their impact on business models.

6.1 Technologies Under WEF Nexus Perspective

In the previous section, the seven units of analysis have been mapped and compared with principles of WEF Nexus Thinking (Table 7). Now, these results are discussed.

Promoting *WEF Security* is a very strong premise of the WEF Nexus Thinking. Securitizing access to Water, Energy and Food is a crucial way to end hunger and poverty (ABBOTT et al., 2017; BENSON; GAIN; ROUILLARD, 2015; HOFF, 2011). All the analyzed technologies increased somehow WEF Security, by promoting more availability of resources, less soil, water and food contamination. Although the majority of the analyzed technologies do not expressly refer to Food Security, this issue is intrinsically implied, since all final activities of the firms studied are related with food production and/or distribution.

Resources efficiency is also important to the concept of WEF Nexus (HARWOOD, 2018; RINGLER; BHADURI; LAWFORD, 2013; YAO; MARTINEZ-HERNANDEZ; YANG, 2018). It is predictable that the technologies implemented increase resource efficiency, since to promote efficiency is the goal in sustainability both environmental and financially. All the analyzed technologies presented themselves as drivers of an increase on resource efficiency. From the analyzed technologies, three of them (AB1, A2 and D1) are directly related to resource reuse. More specifically, technologies A2 and D1 involve effluents treatment and reuse (as by-products in the process or irrigation water).

Livelihood is a construct that stands for the balance between resources supply and human demand (BIGGS et al., 2015). Only technology D1 presents a direct relation with the principle of access/livelihood. Given that the whole project in D1 involves the concepts of agroecology and Social Technology, there is an opportunity to the local community, partners and competitors to incorporate the technology. Hence, the technology implemented could represent more affordable and faire access to water, energy and food to livelihood, in addition to improving financial purchasing power for the families involved.

Research evidences for technologies A1, C2 and D1 show that the implementation of these technologies has direct relationship with the Principle of *Multi-Stakeholder Consideration.* In a WEF Nexus approach, decisions should be made considering a multi-stakeholder perspective (MARTINEZ; BLANCO; CASTRO-CAMPOS, 2018; SUŠNIK et al., 2018; WHITE et al., 2017). Both A1 and C2 implementations interfered on employees work conditions. There was not clear evidence that these technologies affected directly other stakeholders. On the other hand, technology D1, for being a Social Technology, can represent a direct impact not only on farm producer, but also in local community, partners, clients and competitors. The technology implemented in D1 was sponsored by Scientific and Technical Development Agencies, so knowledge developed is accessible to the whole community. Further, the quality of life and work improvement of the family involved in the production can bring about a cascaded progress in local community.

In this research, from the nine WEF Nexus Principles, *"Ecosystem Services*" and "*Local, Regional and Global Scales*" are the WEF Nexus aspects with less adherence points. Ecosystem Services are environmental conditions and processes from which people can benefit (GUERRY et al., 2015; INTRALAWAN et al., 2018). Interestingly, only technology C1 has shown evidences of direct utilization of ecosystem services, as solar energy. It seems that this can be a research agenda. Researchers could explore how technologies could be developed to directly utilize more from ecosystem services as rainwater, river flow and wind, without compromising environment.

In its turn, the only technology that presented a direct relation and concern with the principle of Local, Regional and Global Scales was the case D1, for its alignment with precepts of agroecology, with attention to financial, social and environmental considerations. Again, a WEF Nexus approach can be considered in local, regional and global scales (HUSSIEN; MEMON; SAVIC, 2018; SICILIANO; RULLI; D'ODORICO, 2017; STOY et al., 2018). With the exception of D1, the limited adherence of studied technologies to this principle can be clarified under a private business perspective. In general, the main purpose of businesses when implementing technologies is to promote resource efficiency and competitive advantage, without encompassing the concern of strengthening regional productive capacity.

With the growing urbanization and increasingly limited availability of resources, it is urgent the need to think and apply a WEF Nexus outlook to urban management (ARTIOLI; ACUTO; MCARTHUR, 2017; GONDHALEKAR; RAMSAUER, 2017; TIEN, 2018). From the cases studied, technologies AB1, A2 and D1 showed evidences of alignment with WEF Nexus Principle of *Sustainable Cities*. The main contribution is due less waste disposal in the environment, especially on river waters. In the case D1, besides less waste disposal and soil enrichment with the irrigation using biomass effluents, D1 is a Social Technology, that could be replicated by other actors. However, there was not noticed any active contribution of the mentioned technologies with the purpose of positive impact in terms of strengthening local city and region sustainability.

Clean technologies in the food production chain spin mainly around three aspects. First, clean technologies to obtain energy to the process. Second, alternatives to supply water demand with clean water; moreover, technologies to process what would be waste from the process to further reuse, increasing resources efficiency (ARMSTRONG et al., 2018; MENEGUZZO et al., 2019). All analyzed technologies are clean technologies, since they have reduced or negative impact in the environment. Nevertheless, research evidences point technologies C1, AB1, A2, C2 e D1 as Clean Technologies, in the way that, besides reducing environment impacts, these technologies can reverse potential negative effects into benefits to the process and environment. Only technologies C1 and D1 are directly linked to clean energy generation. The other technologies are predominantly committed to water use reduction and waste process and reuse.

To discuss *Resilience* under the WEF Nexus umbrella is to look for a balance, or even a system reorganization to achieve a social-environmental equilibrium when suffering significant disturbance (GUNDERSON; ALLEN; HOLLING, 2010; SCOTT et al., 2018). In the same sense of “Clean Technology”, although, in a broader perception, all technologies would increase production capacity with the same amount of resources (resource efficiency), this research has evidenced that technologies C1, AB1, A2, C2 and D1 has strengthen system resilience. These technologies presented alternative options to the conventional water and energy supply systems; thus, expanding system's recovery and production possibilities.

Using the WEF Nexus Principles emerged from literature helped to analyze the nature of technologies implemented under a WEF Nexus perspective. Predictably, the features of Resources Efficiency and Water, Energy and Food Security were found in all the seven technologies analyzed, as financial gain through resource efficiency is a strong driver of technological innovation towards sustainability (RANTALA et al., 2018). Consequently, resources efficiency engenders more quality and clean resources availability.

In its turn, principles as Livelihood and local, regional and global scales had very low adherence. Perhaps because their promotion not necessarily has relationship with direct financial gain. It is important, also, to notice that some principles could be better explored when implementing technologies, as Resources Reuse and Ecosystem Services. In addition to contribute to environmental and social sustainability, they can create direct economic value.

D1, implemented by Firm D, had a strong alignment with the WEF Nexus Principles. One of the explanations is that D1 was developed and implemented in a very specific context, of a Call for Projects with focus on WEF Nexus. This indicates the need for public policies and investments' involvement in order to bring more significant and robust changes towards a WEF Nexus management paradigm (KIBAROGLU; GÜRSOY, 2015; SOLIEV; WEGERICH; KAZBEKOV, 2015).

6.2 Implications for Business Models from Sustainability Perspective

Not all technology deployed represents a change in the firm's business model, as business model innovation implies changing some of the elements of the business model (GEISSDOERFER; VLADIMIROVA; EVANS, 2018). However, the technologies implemented show a certain impact on business models, which we discuss in this section.

In this research case studies, all technologies studied were already implemented. It indicates that, in the Business Model Innovation Process, firms would be in the phases of implementation and adjustment (GEISSDOERFER; SAVAGET; EVANS, 2017; MENTINK, 2014; SCHALLMO, 2013).

Seeking to compare and examine the impacts of technologies aligned to WEF Nexus in existing Businesses Models, Table 11 shows data crossing from points of alignment from case studies technologies to Nexus Principles (see Table 7), and evidences of business model innovation, in terms of Value Proposition, Value Creation and Delivery System and Value Capture. In terms of Business Model, each statement that met any Business Model Elements were counted as matching points, representing a quantitative degree of transformation aspects evidenced by each firm.

Firm D had both higher points of adherence to WEF Nexus Principles and evidences of Business Model transformation after D1 implementation. With the exception of Firm D, none of the studied firms had explicitly incorporated WEF Nexus concerns about consumption and waste before implementing the technologies innovations. Moreover, company B was the one with the fewest points of adherence to the principles of WEF Nexus, and the one that felt the lowest impact on its business model after the implementation of this technology.

This research did not show a change in firms' Value Proposition. Generally, disruptive innovations demand a (re)design of Firm's Value Proposition (KHAN; BOHNSACK, 2020). The technologies implemented in the cases were not disruptive innovations. Further, they did not look for modifying the main products and services of the analyzed firms. Hence, they did no boost or impose a Value Proposition (re)design.

Regarding the Value Creation and Delivery System, there was a change in the way of working and mainly in operations. Just like in the traditional system, the prominent change in the Value Capture was financial gain on the part of shareholders/investors/owners. As all technologies sought increase resource efficiency. On employees lives, the major value captured were not financial, but rather improvement in quality of life and possibility for better qualification.

According to Table 11, the relationship between the alignment of technology to WEF Nexus Principles and the Business Model Innovation Elements is not numerically proportional. However, the present research shows indications that the WEF Nexus Principles (Table 7) can support addressing business model innovations challenges (summarized in Table 2).

Table 11 - WEF Nexus alignment x Business Model Elements

Points of adherence to Nexus Principals		Evidences of BMI	**VP**	**Value Creation and Delivery System**			**Value Capture**						
				Human Resources	Operations	Supply Chain and Logistics	Shareholders / Investors/ Owners	Employees	Customers	Suppliers/ Partners	Society	Environment	Competitors
A1	3	7		✓	✓✓✓		✓✓	✓					
B1	2	2			✓		✓						
C1	5	2			✓		✓						
AB1	6	3					✓	✓✓					
A2	6	2					✓	✓					
C2	5	12		✓✓	✓✓✓		✓✓✓	✓	✓		✓	✓	
D1	9	14			✓✓✓	✓	✓✓✓		✓	✓	✓✓	✓✓	✓

Note 4 - VP: Value Proposition

Note 5 - ✗ - No adherence observed. // ✓- Matching point

In order to face and meet some Sustainability goals and needs, companies might struggle with a siloed approach, failing to design and implement innovations that consider other stakeholders (including environment). (DAHLMANN; BULLOCK, 2020; RANTALA et al., 2018). A WEF Nexus approach could help companies to think in integrated solutions to sustainability challenges, creating and capturing more sustainable value (BAZILIAN et al., 2011; DAHLMANN; BULLOCK, 2020; HOFF, 2011).

Implementation of new technologies can reflect the innovation challenge of Opportunity Cost (DESYLLAS; SAKO, 2013). For instance, despite the fact the implementation of new technologies can improve value captured by staff, by fostering a better qualification and improving quality of life at work, it may drive to a decrease in the supply of jobs. This could, for example, harm the value created and delivered for stakeholders inside and outside the company.

From the interviews, it can be inferred that the changes in the business models did not seem planned or even measured. Although the implementation of the technology is thought, planned and studied, there does not seem to be a study on how to better use the technology to create, deliver and capture value for the various stakeholders. This affirmation is supported by respondent from firm D, when he says “Now, one thing they need to structure better is in relation to the business model. We are talking about a technology that will impact production. We have not yet been able to analyze how they have organized his business model and how it will be structured to maintain this entire operation”.

In general, environmental and financial aspects are the main drivers to technological innovations (RANTALA et al., 2018). However, especially in agribusiness context, not to project or measure social-environmental consequences to the technology implementation might represent a challenge to the business model innovation (LONG; BLOK; POLDNER, 2017). A WEF Nexus centered approach can help companies to project social-environmental consequences to the technology implementation and widen value exchange possibilities (BOHNSACK; PINKSE; KOLK, 2014; KHAN; BOHNSACK, 2020; LONG; BLOK; POLDNER, 2017).

The convergence of technologies’ alignment to WEF Nexus Principles and business model innovation points to some reflections. First, there is not a numerically proportional relationship between WEF Nexus features and principles and Business

Model Innovations. The implications of WEF Nexus concerns in the business model innovation process can be fuzzy and not Cartesian, with possible synergies and even more tradeoffs. Hence, it is increasingly necessary that businesses develop an integrative WEF Nexus Thinking instead a siloed thinking towards answering sustainability challenges (DAHLMANN; BULLOCK, 2020; GREEN et al., 2017). Second, technology implementation itself may not be enough to increase crop productivity in agribusiness (ADEBIYI et al., 2020). The impacts and trade-offs effects of these implementations need to be better mapped in the value exchange matrix. And third, rather than just seeing how technology impacts on the business model, it is also important to do the reverse. It is worth to reflect on how the business model can be modified to maximize the benefits of technology for agriculture (LONG; BLOK; POLDNER, 2017).

7. CONCLUSIONS

The purpose of this research was to analyze how implementation of technologies aligned to WEF Nexus affects business models. More specifically, specific objectives include (#1) to identify WEF Nexus principles; (#2) to analyze the technology from a WEF Nexus Thinking perspective and (#3) to analyze how the implementation of new technologies aligned to WEF Nexus Thinking affect business models, in terms of value proposition, value creation and delivery system and value capture.

From the SLR on WEF Nexus literature, ten WEF Nexus Principles emerged (Table 7). These results serve as parameters to drive WEF Nexus management towards more sustainable cities, systems and societies.

The case studies were outlined with four different companies, with seven distinct technologies. Table 3 summarizes information about the companies and their technologies.

This research has contributed to Business Models literature, since it tried to describe changes occurred in Implementation/Adjustment phases of the Business Model Innovation Process (GEISSDOERFER; VLADIMIROVA; EVANS, 2018). It has contributed, also, insofar as it points a WEF Nexus Thinking as a way for surpassing business model innovation towards sustainability challenges.

The idea of WEF Nexus is strongly attached to theoretical discourse about public policies and resources governance (DAHLMANN; BULLOCK, 2020; GREEN et al., 2017; KIBAROGLU; GÜRSOY, 2015). This research has contributed to the study of WEF Nexus and Corporate Sustainability insofar as it offered a practical analysis of technologies aligned to WEF Nexus and their impacts on business model innovation.

This research has also stablished a link between WEF Nexus and Business Model literatures (DAHLMANN; BULLOCK, 2020; GREEN et al., 2017). Much of literature over WEF Nexus revolves around resources management, performance assessment and public policies (GREEN et al., 2017; HOFF, 2011). This research has set up a starting point to incorporate WEF Nexus into businesses.

Research findings indicates that some WEF Nexus Principles that had less occurrence in the technologies analyzed could be more explored by companies. Trying to incorporate mechanisms of resources reuse and utilization of ecosystem services could, in addition to contribute to environmental and social sustainability, they can create direct and economic value.

This research has some limitations. First, the principles of Access/Livelihood, Ecosystem Services and Local, Regional and Global Scales had little adherence to the technologies implemented. This can be a research agenda insofar as researchers could explore how technologies could be developed to directly meet these aspects without compromising environment.

Second, little was perceived about the effects of technologies implemented on Firm's Value Proposition. Future research could explore more about how to rethink Value Proposition design when implementing new technologies aligned to WEF Nexus Thinking. Further, researchers could concentrate in understanding the implications of redesigning Value Proposition from a Nexus perspective.

Future research might look into explore ways of redesigning elements of the Value Exchange Matrix (MORIOKA; BOLIS; CARVALHO, 2018), investigating how business models can be modified in order to maximize the benefits of technology for agriculture, in a WEF Nexus perspective. Also, researchers could explore business model innovation challenges, in order to investigate what hinder innovation and ways of surpassing these challenges.

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APPENDIX A

RESEARCH PROTOCOL

Empresa (Unidade de Análise)	
Responsável	
Nº Funcionários	
Principal Produto ou Serviço	
Área de Atuação	

Programa	Programa de Pós Graduação em Engenharia de Produção (Mestrado)
Título do Trabalho	*Nexus* Água, Energia, Alimento: como a implementação de tecnologias afeta modelos de negócios
Principais Construtos	*Nexus* Agua, Energia, Alimento; Inovação de Modelo de Negócios.

Objetivos e Perguntas de Pesquisa
Pergunta de Pesquisa Como a implementação de novas tecnologias alinhadas ao WEF Nexus Thinking afeta os modelos de negócios de agricultura? **Objetivo de Pesquisa** Analisar o impacto de novas tecnologias em modelos de negócios de agricultura sob a perspectiva de Sustentabilidade e *Nexus* Água, Energia, Alimento. **Questões Guia** • Quais são os princípios do *Nexus* Água, Energia e Alimento? • De que forma os princípios do *Nexus* Água, Energia e Alimento se relacionam com tecnologias para agricultura? • De que forma a implementação de tecnologias para a agricultura impacta modelos de negócios sustentáveis em termos de proposição de valor, sistema de criação e entrega de valor e captura de valor?

APPENDIX B

SEMI-STRUCTURED INTERVIEW SCRIPT

ROTEIRO DE ENTREVISTA SEMI-ESTRUTURADA

1. Que tipo de tecnologia foi implementada na sua empresa?

2. A tecnologia implantada aumenta a possibilidade de reuso e eficiência de recursos de água, energia ou alimento?

3. O que mudou no consumo de água e energia, para produção de alimentos?

4. Alterou de alguma forma a produção de alimentos?

5. Consegue ver mudanças significativas em relação à sustentabilidade?

6. A tecnologia implementada alterou a rotina dos trabalhadores?

7. Mudou alguma coisa na vida de *stakeholders* (funcionários/ sócios/ fornecedores/ clientes)?

8. A implementação de tecnologia proporcionou alguma vantagem competitiva?

9. A implementação da tecnologia alterou de alguma forma os produtos e serviços prestados pela empresa?

10. Houve alguma mudança em relação ao sistema de criação de valor (rotinas e atividades)?

a) Cadeia de Suprimentos e Logística
b) Operações

c) Marketing/Vendas
d) Inovação e Desenvolvimento
e) Cultura Organizacional
f) Governança Corporativa

11. Houve alguma mudança em relação à captura de valor (direta ou indiretamente)? O que mudou na vida dos *stakeholders* envolvidos?

a) Ganho financeiro
b) Sócios / Donos / Investidores
c) Funcionários
d) Parceiros, fornecedores
e) Sociedade
f) Meio-Ambiente
g) Governo