FAKULTÄT II – INFORMATIK, WIRTSCHAFTS- UND RECHTSWISSENSCHAFTEN

THE INSECT ECONOMY

SUSTAINABLE BUSINESS OPPORTUNITIES
BASED ON INSECTS AS BIOLOGICAL RESOURCES

DISSERTATION

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BIOGRAPHY

Maria Real has a Bachelor in International Business and Intercultural Management (2009, Germany) and a Masters in Regional Planning and Environmental Management (2011, Spain). In 2013, she began working as scientific staff member at Heilbronn University of Applied Sciences. The idea about writing about the Insect Economy matured during the first conference about “Insects to Feed the World” in Wageningen 2014. During her research project, she participated in a number of conferences to present her ideas such as ISPIM in Hungary (2015) and Porto (2016), and the G-Form in Kassel (2015). At the G-Forum, the Hans Sauer Foundation awarded Prof. Klaus Fichter and her the Best Sustainable Entrepreneurship Research Award for their paper “Sustainable Business Opportunities in the Insect Economy”. Furthermore, together with René Cerritos she published the article “Pre-Hispanic agriculture practices: Using pest insects as an alternative source of protein” (DOI 10.2527/af.2015-0017). Today, Maria is working as a business consultant in the area of innovation technology.

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ABSTRACT

This doctoral thesis explored, described and characterized business opportunities related to insects as biological resources (research objective 1), and assessed and classified their potential to foster sustainable development (research objective 2). It is embedded in the research fields of sustainable entrepreneurship, particularly related to business opportunities, and both sustainable innovation and sustainable business models. Furthermore, it builds on a sound understanding of the current (global) challenges such as biodiversity loss, hunger and poverty, and the specific solution context of the (Sustainable) Bio-Economy and the Sustainable Development Goals.

The research enterprise of this thesis begins with understanding what insects are from a biological point of view, how they contribute to the resilience of ecosystems (ecosystem services), and how the (human) perception about insects evolved over time. It then continues with exploring insects in the context of academic research. Understanding insects from different angles provides the tools to recognize where business opportunities about insects emerge.

The data sources about business opportunities originated from multiple types of media, including academic sources and secondary literature related to insects. To structure discovered opportunities, the statistical classification of products by activity in the European Economic Community (acronym CPA) and specifically the nomenclatures database RAMON was used. Each opportunity was assigned to a CPA – products of activity (e.g. Products of Agriculture and Fishing), and subcategory (e.g. 01.4 _Live animals and animal products). As a result, seven CPAs and 23 subcategories could be identified and described.

The sum of these CPAs is labeled as the 'Insect Economy.' It is understood as "a subset of innovative and sustainable products, processes, and services based on the use of insects as biological resources and which result from the Bio-Economy." The most prominent CPA sections of the Insect Economy are (1) Products of Agriculture and Fishing, (2) Manufactured Products, and (3) Water Supply, Sewage; Waste Management and Remediation Services. The findings related to the business opportunities in the Insect Economy set the fundament to characterize it in the form of a morphology.

A morphology is useful to study the more general structural interrelations of concepts such as the 'Insect Economy.' The morphology of this thesis builds on its theoretic framework and an extensive literature research about insects as biological resources. It constitutes of categories, dimensions and features. Three overall categories - insects, economy, and sustainability – subdivide 21 dimensions and 141 corresponding features. Eight dimensions and 70 features alone relate to the category of 'sustainability' which shows that the Insect Economy has remarkable sustainability qualities. These comprise among others contributions to 'Sustainable Development Goals,' and 'Sustainable Business Drivers.'

Once the overall set of business opportunities of the Insect Economy and the morphology were determined (research object 1 completed), a subset of the business op-

portunities was selected to assess and classify business opportunities that show potential to foster sustainable development (research object 2). The focus was set on insects related to the food production system, namely insects as feed, food, pet food, and waste converters. The data for the assessment and classification were collected through qualitative interviews with (co-) founders and CEOs which are asked about their business models.

The interview questions focused on eight dimensions of the morphology. Those are (1) Business Model Building Blocks, (2) Business Model Innovation Grid, (3) Sustainable Development Goals (2016-2030), (4) Global Challenges, (5) Sustainability from the Business Case Perspective, (6) Sustainable Business Drivers, (7) Diffusion Dynamics and (8) Risk Factors. For the data analysis, a computer-aided approach was applied, using MAXQDA software.

The data synthesis of the eight dimensions revealed, among others, that the Insect Economy has potential to contribute to 13 out of 17 Sustainable Development Goals and that it is fueled by eight Sustainable Business Drivers. A particularly relevant dimension is that of the Business Model Innovation Grid. It is a practice-oriented tool which aims to inspire businesses to reconceive the way they operate and become more future proof (Bocken et al., 2014).

It is composed of dimensions, sustainable strategies and mechanisms for sustainable business model innovation. The data synthesis revealed that all dimensions and sustainable strategies are covered by the Insect Economy. It further shows that the business models of the interviewed ventures contain numerous mechanisms for sustainable business model innovation. The Centre for Industrial Sustainability (2014) identified 52 of these mechanisms, 17 of them were recognized in the business models of the ventures and three further mechanisms were created during data analysis. Due to the structured format of the Grid and the relevance of the mechanisms for the Insect Economy, it was used for further data classification.

The data classification was done in the form of a typology which helped to cluster identified sustainability characteristics of the ventures in the Insect Economy into ideal types. For the clustering, the typology drew on three dimensions of the morphology. One dimension is that of the 'Business Model Innovation Grid: Mechanisms of Sustainable Business Model Innovation.' It contains the mechanisms which were earlier identified as suitable to be classified into types. The second dimension is the 'Type of Customer' (B2B and B2C) and the third is the 'Innovation Object' ('Product' and 'Processes and Technology'). Both depict the central commonalities to classify the mechanisms and develop ideal types.

The result of this process is a typology consisting of four types: Type 1 identifies Insects as Enablers for a Naturally more Sustainable Food Products; Type 2 identifies Insects as Enablers for Sustainable Food Production Systems; Type 3 identifies Insects as Enablers for Empowerment of Producers, and Type 4 identifies Insects as Enablers for Change in Consumer Behavior.

All in all, describing and characterizing the Insect Economy and particularly sustainable ventures related to insect-based food production systems contributes to the academic fields of sustainable entrepreneurship, sustainable innovation and sustainable business models in at least three ways: First, it introduces the concepts '(Sustainable) Bio-Economy' to the context of sustainable entrepreneurship and develops the concept 'Insect Economy' as contexts for creating innovative goods and services that are consistent with the Sustainable Development Goals. Second, it used a multi-level analysis to systematically develop and to theorize the concept 'Insect Economy.' Third, it advances research about the Business Model Innovation Grid, particularly regarding the mechanisms of sustainable business model innovation.

The Insect Economy creates ample opportunities for further research. The most important one, however, is using the insect-based food production system as a relevant context for sustainable innovation, sustainable entrepreneurship, and business model research. The overall advantage of using this context is that it consists of a broad set of commonalities that the ventures share. This allows for comparability and for conducting quantitative and long-term studies which all of these emerging fields of research are lacking.

ZUSAMMENFASSUNG

Diese Dissertation untersucht, beschreibt und charakterisiert unternehmerische Chancen im Zusammenhang mit Insekten als biologische Ressourcen (Forschungsziel 1) und bewertet und klassifiziert deren Potenzial zur Förderung einer nachhaltigen Entwicklung (Forschungsziel 2). Sie ist eingebettet in die Forschungsfelder des nachhaltigen Unternehmertums, insbesondere in Bezug auf Geschäftsmöglichkeiten, sowie in nachhaltige Innovationen und nachhaltige Geschäftsmodelle. Darüber hinaus baut sie auf einem fundierten Verständnis der aktuellen (globalen) Herausforderungen wie dem Verlust der biologischen Vielfalt, Hunger und Armut sowie des spezifischen Lösungskontextes der (nachhaltigen) Bioökonomie und der Ziele der nachhaltigen Entwicklung.

Das Forschungsunternehmen dieser Arbeit beginnt mit einem Überblick, was Insekten aus biologischer Sicht sind, wie sie zur Widerstandsfähigkeit von Ökosystemen (Ökosystemdienstleistungen) beitragen und wie sich die (menschliche) Wahrnehmung von Insekten im Laufe der Zeit entwickelt hat. Anschließend wird untersucht, welche Rolle Insekten in der akademischen Forschung spielen. Das Verständnis von Insekten aus den beschriebenen Blickwinkeln bietet die Möglichkeit zu erkennen, wo sich unternehmerische Chancen basierend auf Insekten als biologische Ressource ergeben (Forschungsfrage 1).

Die Datenquellen zu den nternehmerischen Chancen stammen aus verschiedenen Medientypen, darunter akademische Quellen und Sekundärliteratur über Insekten. Um die entdeckten Möglichkeiten zu strukturieren, wird die statistische Klassifizierung der Produkte nach Wirtschaftszweigen in der Europäischen Wirtschaftsgemeinschaft (Akronym CPA) und insbesondere die Nomenklaturdatenbank RAMON verwendet. Jede Möglichkeit ist einem CPA – Tätigkeitsprodukt zugeordnet (z.B. Produkte der Landwirtschaft und Fischerei) und einer Unterkategorie (z.B. 01.4 _Lebende Tiere und tierische Erzeugnisse). Auf diese Weise konnten sieben CPAs und 23 Unterkategorien identifiziert und beschrieben werden.

Die Summe dieser CPAs wird als "Insektenökonomie" bezeichnet. Sie wird verstanden als "eine Teilmenge innovativer und nachhaltiger Produkte, Prozesse und Dienstleistungen, die auf der Nutzung von Insekten als biologische Ressourcen basieren und aus der Bioökonomie resultieren". Die wichtigsten CPA-Bereiche der Insektenökonomie sind (1) Produkte der Landwirtschaft und Fischerei, (2) gefertigte Produkte und (3) Wasserversorgung, Abwasser, Abfallwirtschaft und Sanierungsdienste. Die Erkenntnisse über die unternehmerischen Chancen in der Insektenökonomie bilden die Grundlage für die Charakterisierung in Form einer Morphologie.

Eine Morphologie ist nützlich, um die allgemeineren strukturellen Zusammenhänge von Konzepten wie der ‚Insektenökonomie' zu untersuchen. Die Morphologie dieser Arbeit baut auf ihrem theoretischen Rahmen und einer umfangreichen Literaturrecherche über Insekten als biologische Ressourcen auf. Sie besteht aus Merkmalsbereichen, Merkmalen und Merkmalsausprägungen. Die drei Merkmalsbereiche - Insekten, Wirtschaft und Nachhaltigkeit - unterteilen 21 Merkmale und 141 entsprechende Merkmalsausprägungen Allein acht Merkmale und 70 Merkmalsausprägungen beziehen sich auf den Merkmalsbereich ‚Nachhaltigkeit'. Dies zeigt, dass die Insektenökonomie über bemerkenswerte Nachhaltigkeitsqualitäten verfügt. Dazu gehören unter anderem Beiträge zu den nachhaltigen Entwicklungszielen und Werttreibern für Nachhaltigkeit.

Nachdem die Gesamtheit der Unternehmenschancen der Insektenökonomie identifiziert und beschrieben, und die Morphologie die relevanten Eigenschaften enthielt (Forschungsobjekt 1 abgeschlossen), wurde eine Teilmenge der Unternehmenschancen ausgewählt, um jene zu bewerten und zu klassifizieren, die ein Potenzial zur Förderung einer nachhaltigen Entwicklung aufweisen (Forschungsobjekt 2). Der Schwerpunkt lag auf Insekten, die mit dem Lebensmittelproduktionssystem in Verbindung stehen, nämlich Insekten als Futtermittel, Lebensmittel, Heimtierfutter und Abfallverarbeiter. Die Daten für die Bewertung und Klassifizierung wurden durch qualitative Interviews mit (Mit-)Gründern und CEOs gesammelt, welche nach ihren Geschäftsmodellen gefragt wurden.

Die Interviewfragen konzentrierten sich auf acht Merkmale der Morphologie. Das sind (1) die Geschäftsmodellbausteine des Business Model Canvas, (2) das Business Model Innovation Grid, (3) die nachhaltigen Entwicklungsziele (216-2030), (4) die globalen Herausforderungen, (5) Nachhaltigkeit aus der Perspektive von Geschäftsszenarien, (6) Werttreiber für Nachhaltigkeit, (7) Diffusionsdynamik und (8) Risikofaktoren. Für die Datenanalyse wurde ein computergestützter Ansatz mit der Software MAXQDA verwendet.

Die Datensynthese der acht Merkmale ergab unter anderem, dass die Insektenökonomie das Potenzial hat, zu 13 von 17 der nachhaltigen Entwicklungsziele beizutragen, und dass sie von acht Werttreiber für Nachhaltigkeit angetrieben wird. Ein besonders relevantes Merkmal ist das des Business Model Innovation Grid. Es ist ein praxisorientiertes Instrument, welches Unternehmen dazu anregen soll, ihre Arbeitsweise zu überdenken und zukunftssicherer zu gestalten (Bocken et al., 2014).

Es besteht aus Dimensionen, Strategien für Nachhaltigkeit und Mechanismen für nachhaltige Geschäftsmodellinnovationen. Die Datensynthese ergab, dass alle Dimensionen und Strategien für Nachhaltigkeit von der Insektenökonomie abgedeckt werden. Es zeigt ferner, dass die Geschäftsmodelle der befragten Unternehmen zahlreiche Mechanismen für nachhaltige Geschäftsmodellinnovationen enthalten. Das Centre for Industrial Sustainability (2014) identifizierte 52 dieser Mechanismen, 17 davon wurden in den Geschäftsmodellen der Unternehmen erkannt und drei weitere Mechanismen wurden bei der Datenanalyse geschaffen. Wegen des strukturierten Formats des Grids und der Relevanz der Mechanismen für die Insektenökonomie wurde es für die weitere Datenklassifizierung verwendet.

Die Datenklassifizierung erfolgte in Form einer Typologie, die dazu beitrug, identifizierte Nachhaltigkeitsmerkmale der Unternehmen in der Insektenökonomie in Typen zu gruppieren. Für das Clustering stützte sich die Typologie auf drei Dimensionen der Morphologie. Eine Dimension ist die des 'Business Model Innovation Grid": Mechanismen nachhaltiger Geschäftsmodellinnovation'. Sie enthält die Mechanismen, die zuvor als geeignet für die Klassifizierung in Typen identifiziert wurden. Die zweite Dimension ist 'Kundentyp' (B2B und B2C) und die dritte 'Innovationsobjekt' ("Produkt" und "Prozesse und Technologie"). Beide letztgenannten stellen die zentralen Gemeinsamkeiten dar, um die Mechanismen zu klassifizieren und ideale Typen zu entwickeln.

Das Ergebnis dieses Prozesses ist eine Typologie, die aus vier Typen besteht: Typ 1 identifiziert Insekten als Befähiger für natürlich nachhaltigere Lebensmittel; Typ 2 identifiziert Insekten als Befähiger für nachhaltige Lebensmittelproduktionssysteme; Typ 3 identifiziert Insekten als Befähiger für die Befähigung von Produzenten und Typ 4 identifiziert Insekten als Befähiger für Veränderungen im Konsumverhalten.

Insgesamt trägt die Beschreibung und Charakterisierung der Insektenökonomie und insbesondere nachhaltiger Unternehmen im Zusammenhang mit insektenbasierten Lebensmittelproduktionssystemen in mindestens dreifacher Hinsicht zu den akademischen Fachgebieten nachhaltiges Unternehmertum, nachhaltige Innovation und nachhaltige Geschäftsmodelle bei: Erstens werden die Konzepte der nachhaltigen Bioökonomie in den Kontext des nachhaltigen Unternehmertums eingeführt und das Konzept der Insektenökonomie als Kontext für die Schaffung innovativer Güter und Dienstleistungen entwickelt. Beide Konzepte sind mit den nachhaltigen Entwicklungszielen vereinbar. Zweitens wurde mit Hilfe einer mehrstufigen Analyse das Konzept "Insektenwirtschaft" systematisch entwickelt und theoretisiert. Drittens treibt sie die Forschung über das Business Model Innovation Grid voran, insbesondere im Hinblick auf die Mechanismen nachhaltiger Geschäftsmodellinnovation.

Die Insektenwirtschaft schafft vielfältige Möglichkeiten für weitere Forschungsarbeiten. Die wichtigste ist jedoch die Nutzung des insektenbasierten Nahrungsmittelproduktionssystems als relevanter Kontext für nachhaltige Innovation, nachhaltiges Unternehmertum und Geschäftsmodellforschung. Der allgemeine Vorteil der Nutzung dieses Kontexts besteht darin, dass er aus einer Vielzahl von Gemeinsamkeiten besteht, die die Unternehmen teilen. Dies ermöglicht die Vergleichbarkeit und die Durchführung von quantitativen und langfristigen Studien, an denen es in all diesen neuen Fachgebieten noch mangelt.

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION TO THE RESEARCH

1.1 PROBLEM STATEMENT

The world is facing numerous societal challenges, and conventional business practices have been identified as a major cause of those challenges. These practices produce direct and negative impact on the environment as well as the society as a whole. They are known as negative externalities (Porter and Kramer, 2006). The sum of those externalities cumulates into a diverse set of systemic and interconnected problems, known as societal challenges, such as environmental damage, food security, resource scarcity, and health issues (KMPG, 2012, WEF, 2014a).

The large scale and scope of those challenges are reducible to the fact that conventional business practices possess global and systemic relevance. Additionally, they are mainly driven by a dominant business logic of companies considering monetary rewards as the only indicator of value creation (Beckmann and Schaltegger, 2014). Moreover, the framework conditions, such as institutions, incentive systems, and political frameworks tend to support the current system (Pacheco et al., 2010).

In turn, the dominant logic and the framework conditions influence the way companies perceive business opportunities and the way those opportunities are then depicted in business models. The latter is a tool that describes how a firm creates, delivers and captures value (Osterwalder et al., 2005), along with how it materializes in business practices.

In consequence, to produce the urgently needed paradigm shift towards a widespread business practice that mitigates and inverts the challenges, and makes the society resilient, two overall conditions have to change: First, the dominant business logic has to include social and environmental value creation in addition to monetary value creation. Second, companies that adopted social and environmental principles for value creation have to gain systemic relevance.

Different business logic can be found among the so-called ‘sustainable entrepreneurs.’ These are individuals or groups willing to take proactive decisions to pursue sustainability through market- and sustainability-oriented innovation (Schaltegger and Wagner, 2010). In this pursuit, they ideally reach mass markets, thereby contributing to the necessary large-scale transformation.

The large-scale and profound transformation, however, has to reach whole industry sectors and cannot be confronted by a few companies alone. For this endeavor to be accomplished, a large number of companies have to take proactive decisions to pursue sustainability. Incentives will emerge, if they can identify a context which contains a broad spectrum of unsatisfied customer needs backed by a solid economic argument, namely a business case. If this context is then supported by favoring conditions to exploit such unsatisfied customer needs, with the help of suitable political and legal frameworks, it becomes possible to convert these needs into mainstream solutions.

The policy concept of the Bio-Economy (Sheppard et al., 2011) attempts to enable favoring conditions. In fact, it represents a suitable structural framework that consists of well-grounded economic ideas supported by both scientific research in life sciences and enabling technologies related to bio-based resources. Under this configuration, the objective is multiple: enhancing competitiveness and creating new markets, while addressing the societal challenges. Hence, the Bio-Economy holds clear guidelines to provide innovative and sustainable products, processes and services (BioÖkonomieRat, 2015).

Under the umbrella of the Bio-Economy concept, numerous emerging business opportunities around insects as biological resources are flourishing in strategic sectors, such as the food and agricultural sector. Indeed, there are important insect-related industries that stretch back into ancient times, such as beekeeping and silk production. Yet, in the western world, the introduction of insects is a somewhat modern phenomenon. Here, insects as bioresources have attracted both scholarly and business attention mainly by virtue of its attractive potential for sustainability and innovative approaches. Particularly since the release of the report "*Edible Insects: Future Prospects for Food and Feed Security*" (Van Huis et al., 2013) and the conference "*Insects to Feed the World*" (Vantomme et al., 2014) are insects promoted explicitly as a source of feed and food with the aim of alleviating poverty and food security.

However, in the opinion of the author, if insects are to contribute to the necessary paradigm shift in business, the current development around insects as biologic resources needs to be associated to a number of concerns:

1. The focus on insects as a source of food and feed, and as other bioresources attracted research attention principally from the natural sciences (e.g. molecular biology, entomology) and engineering rather than from the social sciences (economics, business management). This is because their focus usually excludes impact assessments or clear sustainable guiding principles which has implications for both innovation and sustainability.

   In fact, there is a long tradition to express sustainability issues in scientific and environmental terms. Its implementation, however, is a social challenge that entails, among other aspects, business mindsets, lifestyles, and consumerism. Hence, sustainable business practices can only be attained by both understanding the underlying dominant business logic and associated processes along with intervening in those processes by applying the concepts and methods of the social sciences.

2. Based on this concern, there is a risk and a tendency that, in the business context, the knowledge emerging from the natural science will be used by applying the dominant business mindset, and will finally lead to conventional business models without necessarily achieving the desired sustainability effect.
3. Furthermore, seeing insects as food, feed, and bioresources is only a partial aspect of the available opportunities. It also prevents seeing them in a more comprehensive perspective, and therefore, gaining a full understanding of the business opportunities and the sustainability potential.

Thus, an academic focus on entrepreneurial approaches around business models, innovation and sustainability seem to be underdeveloped. Similarly, it is possible to explore the market opportunities emerging from using insects as biological resources and their sustainability potential.

1.2 MOTIVATION

Companies have been identified as causes for these problems, but as Beckmann and Schaltegger (2014) notice "companies are both important origins of sustainability problems and central players for their solution."[1] Thus business solutions are needed to promote a paradigm shift. The specific context around insects as biological resources provides a promising context to develop this paradigm shift through innovative business models that include insects.

In effect, the two leading promoters of insects, the Food and Agricultural Organization (FAO) and the Wageningen University and Research Center, focus on insects as solutions for global challenges, primarily to alleviate food scarcity and poverty (Van Huis et al., 2013). To name just a few benefits, insects are natural elements that are readily available on the earth, have a reduced footprint compared to other livestock[2] and are very diverse in species (Paoletti and Dreon, 2005). Besides, the research stream *Yellow Biotechnology* focuses on insects as bioresources to develop new products and services for specific applications in medicine, plant protection or industry (Vilcinskas, 2013a). Those characteristics and the different foci of research on insects provide potential to develop a multitude of innovative sustainable solutions in various industry sectors.

On top of that, the presentations at the Conference on Insects to Feed the World held by pioneering entrepreneurs in the insect-business (e.g., Drew, 2014, Marchant et al., 2014) suggest that sustainable solutions can be brought about. They demonstrated

[1] Proper translation from German into English (Beckman and Schaltegger, 2014, p.322)
[2] To grow one cricket 1.7 times as much dried as its proper body weight. This is much less than beef which needs seven times its body weight, pork which requires 3.8 times as much and chicken which requires the double amount of dried food to grow to its adult stage.

their concern for the state of the world and emphasized that their business models have embedded a certain degree of sustainability.

Sustainability, however, is an ambiguous concept among practitioners and in particular the business context. Here sustainability is often related to efficiency and effectiveness gains - mostly associated with costs alleviation. Furthermore, due to the high degree of unsustainability in the business practices, only slight improvements might already be labeled by them as ‘sustainable.’ Therefore, it is essential to establish a definition of sustainability in the context of insects, which could serve as a reference framework for companies.

In conclusion, there is a sound argument to assume that using insects as bioresources opens up a broad spectrum of business opportunities with intriguing sustainability potential in a number of business sectors. The location and setup as well as their characteristics, however, remain to be determined. Finally, an assessment of already realized business models regarding their degree of sustainability is lacking.

1.3 STATEMENT OF PURPOSE

This research project focuses on identifying and characterizing business opportunities related to insects as biological resources and on assessing and clustering their potential to foster sustainable development. It is carried out within the scholarly field of entrepreneurship which studies “how, by whom, and with what effects opportunities to create future goods and services are discovered, evaluated, and exploited” (Shane and Venkataraman, 2000; p. 218). More specifically, market-oriented practices for sustainable development are addressed in the academic fields of sustainable entrepreneurship, sustainable innovation and sustainable business models. Consequently, they form the fundaments to carry out this research. The Bio-Economy provides the conceptual framework for this research.

In order to address the research purpose of identifying and characterizing business opportunities related to insects as biological resources and of evaluating their potential to foster sustainable development, the research is clustered into two research perspectives:

- The first one adopts an industry sector perspective, namely a meso-perspective. It addresses the research question: *How can emergent business opportunities around insects as biological resources be identified, described and characterized?* To answer this question, I explore and identify past, present, and future business opportunities by organizing them according to the Statistical Classification of Products by Activity (CPA), and I identify characteristics to describe these CPAs. The results of this first research objective are (1) the introduction and comprehensive description of business opportunities related to insects which refers to the concept ‘Insect Economy’ and (2) morphology of the *Insect Economy*.
- The second research question relates to a business level or micro-level perspective: *How can sustainable business opportunities related to insects be assessed and classified?* For this purpose, I will select a subset of identified products by economic activity (CPA) with the most significant potential for sustainability,

which is currently recognized and exploited. Furthermore, I will conduct qualitative interviews with entrepreneurs in this field to assess realized business opportunities in the form of business models and their classification. The result of this second research objective is a typology of sustainable business opportunities in the Insect Economy.

1.4 METHODOLOGY

The ontology of the research question both related to the meso- and to the micro-perspective requires adopting a qualitative research approach. It will enable for a more informative exploratory research. In the following subsection, I will describe the methodology for the development of the morphology and the typology.

1.4.1 MORPHOLOGY OF THE INSECT ECONOMY

Morphological analysis is a method for investigating the totality of relationships contained in multi-dimensional, non-quantifiable problem complexes. It was introduced by Fritz Zwicky (Ritchey, 1998). The term 'morphology' means shape or form and comes from antique Greek, *morphe*. It can be used to study the more general structural interrelations among phenomena, concepts, and ideas, whatever their character might be.

The method is useful to introduce the neologism 'Insect Economy' because it is sufficiently narrow to strip away unintended connotations and surplus meaning, but is conceptually broad enough to capture the underlying essence of the phenomenon (cf. Suddaby, 2010). Thus it contributes to avoiding confusion about the newly introduced concept and allows theory development around it (Weick, 1995)

The total set of possible relationships is described by using multiple dimensions and features to form a grid (Shuring, 1984). It aids theorists to move the analysis to more abstract and theoretical levels. This is the main purpose of this academic work. The resulting grid means to display a cohesive morphology that defines, describes and characterizes the dimensions of insect-based business opportunities within the 'Insect Economy.'

For the development of the morphology, it is important to accurately define and delineate the objective: The research objective of this morphology is to *exhaustively describe and characterize the Insect Economy, namely the business opportunities that emerge around insects as biological resources, and to set it into the context of sustainable development.* The development of the Morphology is delineated by the theoretical framework of sustainable entrepreneurship, sustainable innovation, sustainable business models, and the policy framework of the Bio-Economy. Furthermore, it is restricted to the physical insect, withdrawing it from mimicking the characteristics and abilities of insects. These limitations make it sufficiently narrow to avoid unintended connotations and broad enough to capture the phenomenon.

This morphological grid is derived through non-numeric analysis (exploration) as opposed to the usual data-oriented analyses, e.g., statistical or multivariate analysis. In the morphological grid, every square or box is assigned two or more verbal meanings depending upon the number of required dimensions. Thus, it is a verbal synthesis, and therefore, forces the use of a standard language across disciplines, concepts or alternatives (Shurig, 1984).

The dimensions and features of the Insect Economy arise from both the literature review on theoretical and policy frameworks mentioned above and the exploration of data related to insects. They are re-reviewed in iterative cycles and judged by the principles of fit and relevance. These principles are defined as follows: Fit is related to how closely the developed morphology fits with the ongoing state of the industry. Relevance refers to validating the morphology with stakeholders in the Insect Economy. It tests whether it is of real concern for them and to what extent it captures their attention.

Morphology is an innovation technique used for the practical and theoretical application. Thus, it will aid researchers and practitioners to identify the constitutional and configurable dimensions of the Insect Economy and potential for innovation in this context. Ideally, the morphology will also be understood as a sustainability framework by those who are describing sustainable business models within the Insect Economy and those who are responsible for long-term strategic issues.

1.4.2 TYPOLOGY OF SUSTAINABLE BUSINESS OPPORTUNITIES IN THE INSECT INDUSTRY

The second research enterprise aims to focus on those business opportunities in the Insect Economy which show the most significant potential for sustainability. These opportunities will be assessed and classified in the form of a typology which classifies these sustainable business opportunities into general types.

To do the classification, the typology builds on the morphology of the Insect Economy because it contains the fundamental characteristics of all business opportunities in the Insect Economy. The data for the typology development originates from semi-structured interviews with entrepreneurs, who have realized a business opportunity. It also includes interview questions as well as the data analysis regarding the dimensions of the morphology. Thus, a deductive and inductive approach is chosen to analyze the data. In that way, the empirical study of real cases also serves to test the morphological dimensions and features along with making adjustments.

To cluster the business opportunities, I draw on one or more Morphology dimensions that produced the most meaningful data from the interviews. In the next step, I identify central commonalities among the features of these dimensions. The commonalities form the basis to classify the business opportunities into ideal types. The typology is concluded once the types are consistent and appropriate for the context of the Insect Economy.

The typology serves to evaluate the sustainability of the selected ventures based on one or more characteristics (morphology dimensions). The ideal types can be used as a sustainable framework for practitioners developing and executing sustainable business models within the Insect Economy.

1.5 STRUCTURE OF THE THESIS

Chapter 2 sets the framework for this research project. It reviews the root causes of unsustainability and the implications of sustainability and sustainable development. The latter two concepts are further contextualized into the policy framework of the Bio-Economy. After that, the concepts of sustainable entrepreneurship, sustainable innovation, and sustainable business models are studied and set in the context of (sustainable) business opportunities. By the end of this chapter, the fundament is set to elaborate on the research questions.

In Chapter 3, insect-based business opportunities are identified, described and characterized. These tasks require dividing this chapter into two research approaches. First, insects as biological resources are introduced, and their role in the environment, society, and the economy will be studied. Once the opportunities based on insects are identified, they will be characterized and the characteristics will be structured in the form of morphology.

The objective of chapter 4 is to assess and classify sustainable business opportunities related to insects. For that purpose, qualitative interviews with entrepreneurs who have or are in the process of realizing business opportunities will be carried out. After analyzing the data and synthesizing the findings, the morphology will be updated. Then, one or more morphology dimensions will be related to sustainability in order to identify ideal types of sustainable business opportunities which are visualized in the form of a typology.

In chapter 5, the reflections regarding the research findings will be considered and set in the context of current research around sustainable entrepreneurship, sustainable innovation, and sustainable business models. I further make recommendations, assess limitations of this research project and suggest future research objectives, before drawing the final conclusions

CHAPTER 2: SETTING THE FRAMEWORK

2.1 GLOBAL CHALLENGES: DIMENSIONS AND ROOT CAUSES

The world is undergoing multiple profound and globally relevant transformation processes with the power of undermining humanity's long-term prosperity. Indeed, humanity is in a position that further human pressure may lead to large-scale, abrupt, and potentially irreversible changes (Griggs et al., 2014). Accumulating research shows that a prerequisite for future human prosperity is the stable functioning of Earth‘s life support system, and this functioning is at risk (Rockström et al., 2009). Therefore, the relationship between our socio-economic systems and the planet require fundamental reevaluation to collectively ensure that these risks are not realized.

The transformation processes are also known as *global challenges* which refer to interdependent and globally relevant problems. They are also widely recognized as *global risks* when uncertainty about their occurrence exists (United Nations, 2016a), or as *mega-trends* when they represent long-term pattern currently taking place contributing to amplification of global risks and/or altering the relationship between them (PWC, 2015). In both cases, the challenges are characterized by being "*transnational in nature and trans-institutional in solution, requir[ing] collaborative action among governments, international organizations, corporations, universities, NGOs (non-governmental organizations), and creative individuals.*" (Glenn et al., 2014; p. 17)

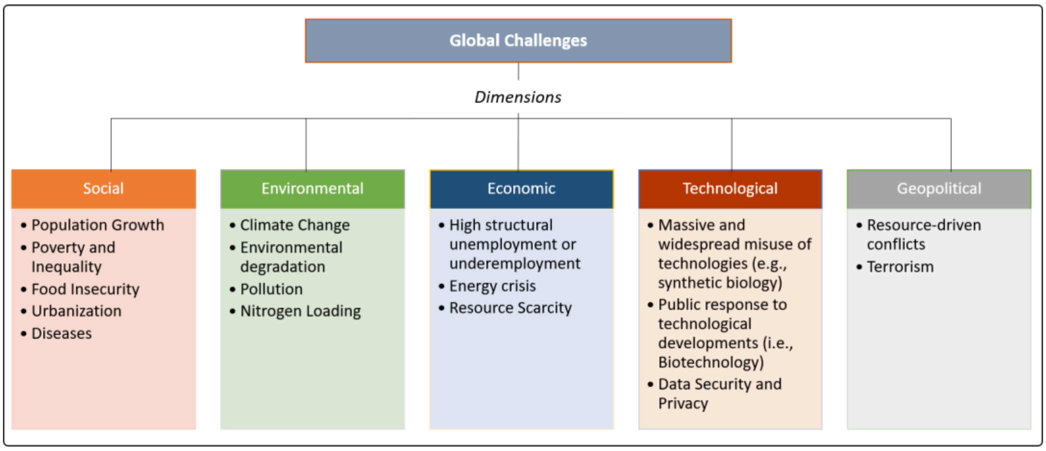

Figure 1: Global Challenges
Source: Chart based on World Economic Forum (2015, 2010, 2005), the Millennium Project (Glenn et al., 2015, 2014), United Nations (2016a), KPMG (2014, 2012), and PWC (2015)

Already in 1987, the Brundtland Commission (WCED) intended to formulate an interdisciplinary and integrated approach to address these global challenges. Since then, considerable effort has been made to fully comprehend their root causes and implications and to simplify the complex scientific concepts that are related to it due to many layers and density. Sound analysis was undertaken, e.g., by the World Economic Forum (2015, 2010, 2005), the Millennium Project (Glenn and Florescu, 2015, 2014) and the United Nations (2016a). Those organizations provided reports repeatedly confirming the very same five dimensions originally detected in 1987 as dimensions of global challenges. Figure 1 provides an overview of these dimensions, namely the social, environmental, economic, technological and geopolitical dimensions, which were extracted from several of the reports above.

On the one hand, economy-related activities and population growth together with geopolitical power have been identified as important drivers for inequality and poverty. On the other hand, economic and population growth along with poverty are identified as root causes of environmental deterioration. Finally, both the technological and the geopolitical dimensions were determined crucial for human development because advances in both were and still are used as enablers for economic growth. Both can potentially solve societal problems when wisely employed considering the social and environmental context. However, a myriad of systemic dysfunctions among the five dimensions has been detected - each with intrinsically destructive behavior patterns reinforced by the combination of dimensions (WCED, 1987).

These multidimensional cause-effect relationships are not new to human history and trace back to the very beginning of the last century (Mebratu, 1998). Altogether, population growth, conventional business practice dysfunctions, and globalization enlarged the problems. Even if they were once local or regional, nowadays, they cause global concern. In this view, socio-economic development and global sustainability are frequently being posed to be in constant conflict, resulting in environmental destruction, ecological resource scarcity, and social inequality and poverty, among other societal challenges.

The next section addresses the root causes of the global challenges according to the dimensions. The focus lies on the social, the economic and the environmental dimension as they form the fundamental core of the human condition (Heinrichs et al., 2016). The geopolitical and technological dimensions are left beside as they can be considered means to improve global challenges or to further aggravate the situation depending on the way they are used. Since the human system is organized to enable people to satisfy their (basic) needs (e.g., food, access to health care, and education) through the exchange of money, the economy is inseparably linked to society. Therefore, the social and the economic dimension are bundled into the socio-economic dimension.

2.1.1 ROOT CAUSES RELATED TO THE SOCIO-ECONOMIC DIMENSION

This thesis argues that long-term sustainable development needs to be conceptualized in terms of an optimal equilibrium between economic growth and social equity as well as well-being for which a transformation process is required. This process is closely related to both lifestyles and consumption patterns, and production modes which are linked directly to the pressures on the planet along with the wealth distribution practices in society. Hence, to understand the current systemic crisis, it is necessary to explore the functioning of the combined socio-economic dimension, including their current economic structures, their institutions, and internal power relationships (Griggs et al., 2014).

Historically, it is narrated that one root cause for the global challenges lies in exponential growth related to both economy and population (Meadows et al., 2004). This economic growth paradigm, among others driven by population growth, produces multiple adverse effects. These effects emerge because the growth paradigm is based on ecological resources which are being used at a faster rate than they can be replenished, offset, or substituted. In fact, this rate of increasing consumption of physical goods is reaching *planetary limits*. Moreover, because there is a delay in recognizing those limits, this growth paradigm is producing an *overshoot*, which is why conventional economic growth materializes in the global challenges (Meadows et al., 2004).

Furthermore, the reasons for the overshoot are argued to lie in the dominant business logic of companies that consider only monetary rewards as overall incentives for its value creation processes (Beckmann and Schaltegger, 2014), disregarding the *true cost of production*. However, in addition to economic value, this process should consider the negative impacts on both the environment and the society, the so-called *negative externalities* (Porter and Kramer, 2011). In a very general way, economic business imperatives often prevail over societal values as corporations strive to mitigate costs and reduce uncertainty, improve product availability and, more importantly, attain room for further growth.

The economic system that promotes the described overall business logic is known as *material* or *linear economy*, which is understood as the process of resource extraction, production, consumption and waste generation. In this context, the transfer price in the marketplace is the only focus among businesses, and the only place to really exert some useful effort to promote sustainability is mainly limited to improvements in production patterns by eco-efficiency and resource substitution (Dyllick and Hockerts, 2002). However, this sustainability approach focused on the reduction of negative externalities and the contribution to environmental goals is still insufficient to solve (global) environmental problems and social challenges.

This situation has been of major concern for academic scholars, politicians, nongovernmental organizations, and business leaders alike, who aim to improve the quality of life by solving (global) environmental and social problems. In practical terms, the impetus is on coming back to some sort of rational standard of sustainable application, not just what businesses should do in some sort of utopia. In this context, the following questions emerge: What is sustainability? How important is sustainability? What is the true basis for sustainability? What are the practices and best uses in business? What are the factors that thrive or diminish it? How can the tensions between sustainability and business performance be softened? What is the right balance there? Answering all these questions is required to counterbalance common business practices and their attached dangerous effects.

In day-to-day practice, businesses frequently reach a position where the future destination is no longer clear. Economics and Business Management are still struggling to become an exact science, since - at this point - the socio-economic systems are not fully understood with any real success. In an uncertain scenario with a range of options, the consequences of exploiting new things are unknown. Business decisions cannot be made through an optimization process in the same way as mechanical calculations are made in response to a given set of alternatives at any moment. Clearly, the current understanding and the complexity of the socio-economic system is such that *the right* way to develop can never be found. All that is known is that there are wrong ones.

Even though the collective theories of markets, organizations, and change still keep the understanding of the business landscape incomplete, the quest for economic growth and social equity has evolved towards a broad set of sustainable practices at the business level. Good practice solutions implement a system-wide or value network perspective in order to achieve a *net-positive social and environmental impact* in addition to economic value (Forum for the Future et al., 2014). This new way of thinking about the way businesses can serve and accomplish their purposes is based on the conjecture that a set of resources are not put to their 'best use.' In consequence, certain modes of business operations are no longer tenable, and not all profits are created equal: Clearly, those that carry a societal benefit are better.

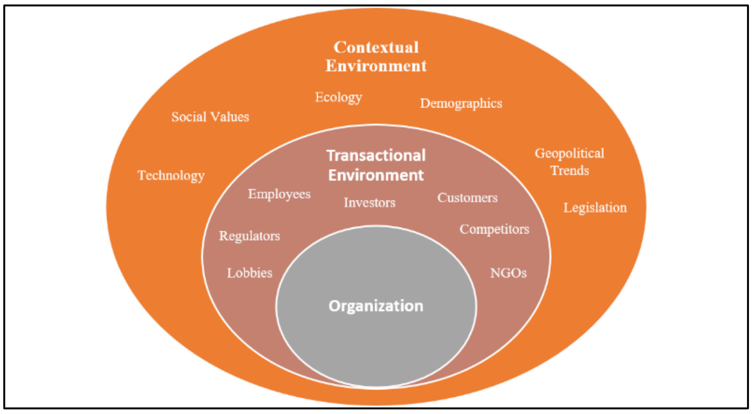

Figure 2: Contextual Environment of Businesses
Source: (Ramírez et al., 2017; p. 33)

At this moment, the old discourse on the role of businesses in society is changing by social pressures and reality-checks. It drives a growing amount of companies and corporations to adopt an open and collaborative approach. By these means, the aim is to get individuals and groups at all levels and functional backgrounds within their organizations to examine the array of factors that contribute to sustainable development. In the process, reframing of collective understanding of their conventional business practices occurs. The goals of this process are to reshape the way business is conducted and to improve the way companies listen to the broader community, and not only their immediate *transactional environment* (see Figure 2). Ultimately, business is a powerful force for positive social change since it has proven a powerful force for the opposite.

This new mode of business creation sees meaning and value as a result of eliminating that myriad of systemic dysfunctions within and among the five dimensions of the global challenges. The new mode focuses on the long-term rather than the short-term. In that way, it avoids the dominant present-focus bias characteristic in conventional business practices and instead, does a self-reflection about its role in society as a whole. By looking for social validation, or the *social case*, businesses will not only optimize existing means-ends frameworks but will discover, create and exploit completely new means-ends relationships for the purpose of value creation. In this regard, they can reduce the dissonance between the economic and the social dimensions altogether. It is an evolution that can be seen as the same process where nature tries to adapt or resonate with its environment in harmonic equilibrium.

2.1.2 ROOT CAUSES RELATED TO THE ENVIRONMENTAL DIMENSION

The previous explanations of the dominant business logic elucidated that human activities have a significant and escalating impact on the natural functioning of the environment. To which extent humans are interfering with the natural function of the environment can be measured by the *Ecological Footprint*. It assesses human consumption regarding bio-resources needed to balance the demand for services and products, and the natural sinks need to absorb the waste produced by the average global citizen/firm (Global Footprint Network, 2016). Substantial scientific evidence indicates that human activities are reducing both the ecosystem resilience and its biocapacity, thereby affecting many forms of social and economic development.

There are at least nine *planetary boundaries* that should be respected to guarantee safety for humanity (see Figure 3). Nowadays, four out of the nine boundaries have already transgressed and are responsible for large-scale health and economic impacts (Steffen et al., 2015): namely climate change, loss of biosphere integrity (which included, e.g., biodiversity loss), land-system change, and altered biogeochemical cycles (which includes the geochemical flow of phosphorus and nitrogen). Ocean acidification is about to reach its boundary. Scientists estimate that once these limits are reached, they can touch critical tipping points and subsequently cause sudden loss of biological productivity reducing the capacity to support human life.

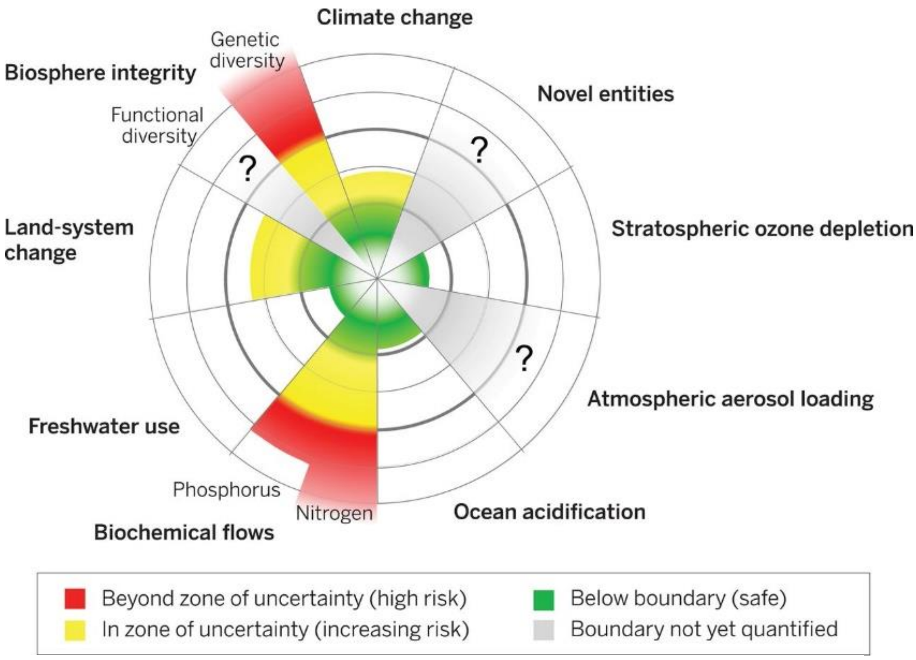

Figure 3: Planetary Boundaries – Safe operating space for humanity
Source: (Steffen et al., 2015)

However, the bio-capacity should not be viewed as a constant, but as submitted to change. For example, the consequences of climate change—even though predictable only to a limited extent—will free new set of natural resources and perhaps agricultural land, which can become subject to human activities, something that to date is not possible. Because the concept of bio-capacity remains open for precise clarification, societal activities should follow certain principles and values (Kates et al., 2005) such as avoiding to produce any ecological deficit. Instead it is possible to rebuild ecosystem resilience and increase bio-capacity.

It is known that certain business practices deteriorate natural ecosystems upon which they must be based and which are necessary to support long-term human prosperity. For that reason, business as usual (BAU) - meaning the continuation of growth trends from the past without serious decoupling of growth from waste production and environmental degradation - will not be possible in the near future. This explains why the environmental dimension is taking superlative functional significance in business practices, helping to orient business across time. Ultimately, the *natural case* is seen as a driving force to solve part of the crisis humanity is facing – socio-political, environmental and economic - allowing a new round of wealth creation.

Companies in search of the aforementioned rational standard of sustainable application tend to go beyond their (immediate) transactional stakeholder environment to build their new sustainable identity. That way, they enter into a constant cycle of acceptance and acknowledgment of the importance of the natural case in business. This process is systematically sustained by their daily choices in every socio-economic interaction. The resulting chain of reaction will ultimately define their individual ability to overcome any perceived trade-offs between socio-economic development and global environmental sustainability, paving the way to re-defined operational modes.

In a broad interpretation, the striving for a natural case brings companies closer to the notion of sustainable development because they decouple economic growth from environmental destruction. In that way, they solve current tradeoffs of a growing world population, potentially enable higher standards of living, and manage the effects of production and consumption on the global environment. Furthermore, the combination of the natural and social case makes consumption preferences and operational processes compatible with the environment and society because it bases on investing in value-creating activities for nature restoration and human development.

Hence, instead of producing negative externalities, socio-economic activities should produce positive externalities or a *net positive* to avoid further overshoot and possibly a point of no return—if it is still available (Weisman, 2013). The solution implies a profound societal transition, which enhances the resilience of the Earths' life support systems. With no doubt, the private sector must play a central role in achieving such a goal.

2.1.3 CONCLUSION

The chapter displayed that global challenges are the result of a myriad of systemic dysfunctions. As they do not have a simple cause, they do not have a simple solution (Mebratu, 1998). The solution consists in a profound societal transition so that the Earths' life support systems can regain their resilience. The private sector must play a central role in achieving that goal. To achieve it, the underlying linear economic system needs to be transformed by rethinking the supply and demand side.

The supply side has to reconsider the way it uses resources; this concerns the type (renewable and non-renewable sources) and/ or flows and/ or activities related to resource extraction and use (Robèrt et al., 2002). Moreover, innovations around technological development will be crucial for sustainable development. To avoid errors from the past and ensure their contribution to sustainability, innovation should be developed considering potential risks (von Weizsäcker et al., 2009).

Demand can be considered the most important driver for change, especially in a world where the population is exponentially growing and every individual longs for food, shelter, and copious amounts of additional goods and services. Satisfying this demand under conditions of decreasing or stagnating supplies of energy, water, land, and minerals will provide no alternative to rethinking current business practice (BAU) (von Weizsäcker et al., 2009).

To make international demand and supply streams beneficial for all involved, economic development must reach the worlds' poor and contribute to improving their living conditions, while the affluent must adopt lifestyles within the biocapacity of the planet. This is fundamental because the issue of environmental sustainability is intertwined with that of poverty and inequity, and without the sustainability of ecosystems, the functioning of the global economy cannot be guaranteed (WCED, 1987).

Furthermore, international exchanges need to significantly reduce their waste production and pollution. As the planets' sources are limited so are the planet's sinks. Only if waste can be recycled, absorbed or rendered harmless is it produced in a sustainable manner (Daly's' law of sustainability) (Meadows et al., 2004). Zero waste production is not only fundamental to preserve the planet's life support system and human health, but it is also an opportunity to maintain the resource base for the world economy to function in the future.

All in all, the transition towards a resilient society and a sustainable economic system can be considered to be the main challenge of the 21st century (Meadows et al., 2004). It will require radical shifts in lifestyles and the way goods and services are designed, produced and used. Until present, current efforts of sustainable business practices can be safely assumed to be insufficient in decoupling from counterproductive business practices (Elkington, 2012). To make those far-reaching shifts, the status quo demands a profound rethinking – a process that requires an entrepreneurial spirit and disruptive innovation.

2.2 SUSTAINABLE DEVELOPMENT: TOWARDS A SUSTAINABLE ECONOMIC SYSTEM

The term sustainability is used on many occasions, but rarely with the same meaning. In their daily use, sustainability tends to identify long-term ability to maintain a system in balance or a steady state. In different disciplines such as biology or economics, it is applied to different systems and thereof used with different meanings. For this reason, the use of the term is loaded with ambiguity when applied to the socio-economic system, and it is almost impossible to find a unique and accepted definition of sustainability (Kates et al., 2005). The lack of a common definition hampers a productive dialogue based on the collection of relevant critical facts and opinions. Instead, it produces biased, partial and unrealistic conclusions.

In 1987, the U.N. World Commission on Environment created "transcendent" definition of sustainability attached to the word development, as development that "meets the needs of the present without compromising the ability of future generations to meet their needs." Since then, both biological and economic science scholars have been dealing with this abstract imposition that is merely trimming around the edges of the challenges, trying to create a useful framework for corporate sustainability and optimize the existing amount of uncertainty in practical terms.

After decades-long analysis and discussions, a new sustainability definition has emerged attached to the word development: "*one that results in improved human well-being and social equity while significantly reducing environmental risks and ecological scarcities based upon a combination of low-carbon growth, resource efficiency, and social inclusivity*." The next section describes the journey that the term has passed through.

2.2.1 THE HISTORY OF SUSTAINABLE DEVELOPMENT

The concept of *sustainable development* emerged in the context of a growing awareness of a looming ecological crisis and can be considered the socio-economic driving force of western history in the period around the end of the 20th century. Although the concept itself stretches back into antiquity, as already the Romans recognized an environmental impact in their land management processes, it was later in the 18th century when scarcity of wood made it difficult to satisfy European strategic economic activities (such as construction, heating, ship-building) when the concept of sustainability became relevant. (Mebratu, 1998)

The fear that such a shortage would threaten the basis of people's existence encouraged a new way of thinking in favor of the responsible use of natural resources in the interest of the present and future generations. Even claims were raised that the consumption of resources should be restricted (Du Pisani, 2006). However, rather than forming a balance with nature, the industrialization of the economy led people to believe that it was right for them to dominate the natural order and radically transform it into consumer goods.

Furthermore, it was believed to be necessary and acceptable to ravage the landscape in the pursuit of maximum economic production, and that only the goods produced by industry and placed on the market for sale have value. In the end, instead of imposing restrictions, technological innovations open new possibilities by facilitating using new resources. This made intellectuals/philosophers of the time believe that innovation would allow economic progress while step by step reducing its impact on nature and entering into balance with it.

Later on, ongoing industrialization and two consecutive world wars led to raising awareness on the value of nature among society. Book publications such as Rachel Carson's *The silent spring* (1962) and Paul Ehrlich's *The population bomb* (1968), as well as movies and television programs contributed to the spreading of consciousness. The first non-governmental organizations and green political parties formed at approximately this time (1960s) (Creech, 2012).

The topic picked up speed in the 1970s and 80s. That was the time when the Earth Day was first celebrated and indicated that society was accumulating ecological debt over the time of a year. It was the time of the OPEC oil crisis and the Amoco Cadiz oil spill off the coast of Brittany. Additionally, the first edition of the Limits to Growth was published which simulated a number of scenarios on human development. This publication made clear that scientific and technological advances were not sufficient to sustain growth in the future and a change in lifestyles and consumption patterns was unavoidable (Meadows et al., 2004).

Important institutions were created that still today support this message and inform about the current status. These institutions are for instance the World Watch Institute (1975), which since 1984 publishes the State of the World report; the World Resources Institute which since 1986 informs about the state of the worlds' resources and the International Panel on Climate Change (IPCC), which provides information about climate change. It was also the time when the Grameen Bank started to provide microcredits to the poor (1983).

In addition to these milestones, significant scientific findings were published such as the discovery of the Antarctic ozone hole (1985) and the prediction of climate change (1985). The startling scientific discoveries were accompanied by devastating events such as the environmental and social catastrophe of the Bophal accident (1984) during which the leak of toxic chemicals led to 10.000 dead and 300.000 injured people. Moreover, the drought in Ethiopia (1984) should be mentioned, which left more than

500.000 people to die from starvation as well as the Chernobyl nuclear station accident (1986) and the Exxon Valdez tanker oil spill (1989).

In consequence to these events, the right time arrived to spread the idea of 'sustainable development', which received particular attention by the World Commission on Environment and Development (WCED) better known as the 'Brundtland Commission.' The commission was composed of representatives from both industrial and developing nations, and it established the famously known definition of sustainable development, namely "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." It combines categories that need to be sustained - nature, life support systems and communities - and categories that need to be developed - people, economy, and society (Parris and Kates, 2003).

This definition is clearly the result of political correctness, which tries to consolidate the compromise between growth and conservation. From a puristic point of view, the idea of sustainability or conservation and the idea of development are seen as a contradiction in itself. In fact, it produced controversy due to its high degree of imprecision. For instance, the understanding of sustainable development varies depending on the context, culture, and knowledge (Heinrichs et al., 2016). This has led to a situation, where a clear and immutable meaning of the term remains elusive (Kates et al., 2005).

Nonetheless, the introduction of the concept by the United Nations leveraged its significance in the world economic order, which led to an inevitable rebalancing of national priorities despite the imperative not being accepted by all countries. In fact, the definition laid the ground for the Rio Conference on Environment and Development in 1992 which marked the first international endeavor to develop action plans and strategies for moving towards a more sustainable form of development. From this event on, sustainable development became institutionalized by a system of international political meetings such as World Summit on Sustainable Development (2002) and Rio +20 (2012) (Olsson et al., 2014).

Decision-making within those political institutions has been tough, among others because of the inherent ambiguity of the concept 'Sustainable Development'. Despite dissent, the international community is gradually reaching a common understanding. The community has more or less concretized a policy initiative on sustainable development (Olsson et al., 2014). In fact, it approved two internationally agreed voluntary and time-bounded targets. The first agreement was the *Millennium Development Goals* (MDG, 2000 - 2015). It was the largest-ever agreement among world leaders to set a number of time-bound and measurable goals for combating poverty, hunger, disease, illiteracy, environmental degradation and discrimination against women. The second agreement is the Post-2015 Goals or Sustainable Development Goals (SDG) in force between 2016 and 2030 (see Figure 4).

Figure 4: Sustainable Development Goals
Source: Illustration based on United Nations (2016b).

While the Millennium Development Goals primarily focused on human development regarding poverty alleviation in the developing world, the SDGs consider the main causes of poverty, gender inequality, and the holistic nature of development, including a sustainable economic system. Hence, they reflect a more in-depth understanding of the interconnectedness of social, ecological and economic systems (Foxon et al., 2013). The 17 goals and 169 "action-oriented [targets are] global in nature and universally applicable, taking into account different national realities, capacities and levels of development" (United Nations, 2016b; p. 10).

Interestingly, this increased interconnectedness also improves the understanding of the linkage between the role of businesses and sustainable development. The SDG Compass uses this potential by providing guidance for companies to align their strategies and their contribution to realizing the SDGs (see https://sdgcompass.org/). This aspect is further addressed in the following section.

2.2.2 BUSINESS AND SUSTAINABLE DEVELOPMENT

Active stakeholders in the field of sustainable development have long disregarded the role of businesses. In their eyes, business and economics were the origin of evil and, therefore, were broadly left aside during the decision-making processes.

This idea of evil business can be explained by the belief of many business people that technological innovations would solve any future scarcity. This mindset is known as *technological optimism*. Technological optimists assume that elements of the natural environment and society are represented as resources or ‘capital.’ For them, natural capital (soil and natural resources) and economic capital are fully substitutable because increasing efficiency and technological advances are believed to enable increasing utility even without natural capital (O'Hara, 1997, von Hauff, 2016). This concept of full substitutability where technological optimism prevails is known as *weak sustainability*.

These assumptions explain the mental model behind the root causes of the global challenges such as the disregard of externalities (emission of waste, pollution, and toxic materials) and the overshoot that the system produces beyond the carrying capacity of the planet. Disregarding the externalities leads to market failure = causing ever larger globally relevant challenges.

Especially those companies which depend on excessive requirements for virgin resources will be confronted with difficulties to obtain their license to operate because they are competing in sensitive local resource markets. In fact, the unethical corporate behavior is increasingly affecting the company’s image. Elkington (1994; p. 95) lists the products and technologies that were in the firing line between 1960 and 1990. He shows that the societal pressure has been increasing since the 1960s and is affecting ever more industry sectors. Especially the chemical industry and the agricultural sector (farming, fishery, and forestry) are in focus, as well as water supply and waste management.

Those industry sectors are also under fierce pressure under the light of climate change. In 2010, 35 percent of greenhouse gas emissions were released by the energy sector, 24 percent (net emissions) from AFOLU (agriculture, forestry, and other land use), 21 percent by industry, 14 percent by transport and 6.4 percent by the building sector (IPCC, 2014; section 1.2). These figures demonstrate the high systemic relevance of these industries. Thus, they may be prone to considering disruptive business solutions towards sustainability.

International institutions, international political meetings, and science have made sustained effort to change this mental model. For instance, the International Institute for Environment and Development was created to seek ways for countries to make economic progress compatible with the available environmental resource base. The Business Council for Sustainable Development, which is an organization led by leaders of more than 200 prominent businesses and partners are collaborating to accelerate the transition to a more sustainable world.

Scientific contributions bridged the gap between economics and natural sciences by providing clarity on the societal impact produced by the businesses. A milestone was the introduction of the *ecosystem services* concept. It assigns economic value to ecosystem functions and ecosystem goods and services (Constanza et al., 1997). Monetization allows quantifying negative externalities in economic terms. Besides, the Stern Review (2006) makes a convincing economic case. It states that the costs of inaction on climate change will be up to 20 times greater than measures required to address the issue by the time it was published.

Due to these publications, the concepts of sustainability began to resonate with business leaders because they displayed how companies are contributing to societal problems when disregarding negative externalities. In turn, forward-looking leaders gained insights into the ways they can produce a business case to escape this dilemma and assure the long-term viability of their business.

The Johannesburg World Summit on Sustainable Development in 2002 can be considered another milestone to interconnect business and sustainable development. It was during this summit when the concept of 'sustainable consumption and production' was introduced and led to a number of international agreements. The key principle was to establish a link between productivity, resource use, and levels of pollution. Specifically, the agreement was about (Edwards, 2010):

- Ensuring that economic growth does not cause environmental pollution at a global and regional level
- Improving efficiency in resource use
- Examining the entire product lifecycle
- Providing more transparency to consumers by making more product and information available to consumers
- Exploiting taxation and regulation to stimulate innovation in clean technologies.

The agreements, for instance, stimulated investment in new energy technologies and in new ways of recycling or reusing waste. They also encouraged the development of concepts linked to sustainability such as *added value* and *cradle to cradle*. Since more information was being made available to consumers following the summit, product developers benefited from both the environmental credentials when being displayed on products and the pressure for more green solutions which better-informed clients expected (Edwards, 2010).

It is therefore not surprising that the OECD (2009b) found that the green economy ideas became mainstream and that national governments invest a portion of their economic stimulus in environmental actions. In fact, China made massive efforts to become the world’s largest domestic market for wind power by 2010, exceeding its target for installed capacity by 320 percent and in 2011, began its shift towards a green economy according to its 12th five-year plan for economic development. Both, China and India are nowadays considered leaders in sustainable development. (Creech, 2012)

The link between the business sector and the achievement of sustainable development was further strengthened when the business sector became an integral part of the Sustainable Development Goals (SDGs, 2016 – 2030). They are designed in a way that synergizes between societal and business interests are maximized, and trade-offs are managed. The design includes specific national (and local) agenda conditions such as financial support, government policies, and R&D transfer to influence entrepreneurial environments that sustain the bio-resource base for the world economy to function. (Griggs et al., 2014)

Another approach to aligning business interests with the SDGs was the creation of a Private Sector Advisory Group. It was set up by business leaders of major companies from various industries worldwide to collaborate and discuss practical solutions about the common challenges of contemporary sustainability and to implement related solutions. Expected contributions of this group are for instance the development of business models and capacity building. Thus, the business sector is obtaining a central role in the process of achieving a sustainable future.

Hence, the world is seeing a transition from *weak sustainability* towards *strong sustainability* in which capital produced by humans is only complementary to natural capital. This means that it is only to a limited extent substitutable because a critical level of natural capital is necessary to avoid irreversible losses. Such transition is fueled by the increasing scale and scope of adverse impacts produced by the business sector, which at the same time threatens the viability of the economic system (Moore and Diaz, 2015).

For this reason, a large-scale and collective economic change is required around the globe (Borel-Saladin and Turok, 2013, IPCC, 2014). It should promote solutions to address global challenges and build resilience "to maintain and enhance the desirable properties of environmental integrity, social equity, and human well-being under transient shocks and enduring stress, both internal and external to the system" (Foxon et al., 2013; p. 193).

International institutions need to support this transition and make a sustained effort to create a coherent socio-economic system with the aim of maintaining a sense of continuity towards sustainable development. Complimentary to that, science should play a 'trusted advisor' role by signaling the opportunities holding both ecological and economic benefits, while explicitly incorporating social goals. Finally, the most significant place to put faith on is engaging in an honest conversation about sustainability and its implications in the public arena.

2.2.3 CONCEPTS, PRINCIPLES, AND FRAMEWORKS OF A SUSTAINABLE ECONOMIC SYSTEM

The idea of what describes a sustainable economic system is becoming more tangible. Conceptual frameworks, practical tools and the direct linkage of the Sustainable Development Goals (SDGs) as well as the business sector contribute to this clarity. An example is the *Global Value Tool Navigator* (2017). The navigator uses the SDGs as a compass to orient companies in sustainable decision-making. It links the SDGs to further tools that fit specific situations, such as the development of new products in a sustainable way, which then serve businesses to assess, measure and manage impacts on sustainable development.

When used this way, the SDGs can guide companies to better align their business models with their evolving sense of societal purpose creation. Furthermore, new concepts of sustainability, principles, values, and frameworks such as the nested concept of sustainability, The Natural Step (TNS) and Natural Capitalism guide this transition. Those three concepts are presented in the following section.

THE NESTED CONCEPT OF SUSTAINABILITY

Among the early schematic illustrations of the sustainability concept was the profile of a Roman temple. Its roof symbolized sustainability stabilized by three pillars: the social, the environmental and the economic pillar. This illustration led businesses to select one or two pillars and consider the company to be sustainable (Fifka, 2011). This visualization was then followed by the illustration in the form of a Venn-diagram of three cycles. Each respective cycle represented the social, environmental and economic dimension of sustainability and intersected in several positions. This illustration however also disregarded the fact that the environment builds the fundament of society, which in turn is catered by the global economy (Griggs et al., 2013).

The latter misconception was corrected by the 'nested concept' visualized in Figure 5. The Nested Concept well reflects that without an intact functioning of the natural environment neither society nor the economy would function. It further visualizes that the economic system is merely a sub-system of society.

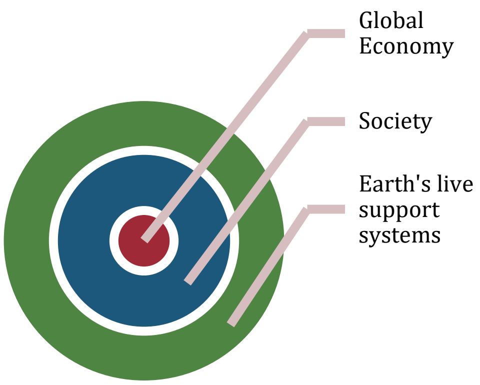

Figure 5: "Nested" Concept of Sustainability
Source: Chart based on (Griggs et al., 2013)

In reality, however, the linear economy dominates the environment and the social system functioning as a key driver for the global challenges. The necessary balance among the three systems can be achieved by applying the principles of The Natural Step (TNS) and Natural Capitalism. Both are approaches to sustainable development.

THE NATURAL STEP

The Natural Step provides a framework to guide concrete actions through basic principles of sustainability. It can be seen as a means to establish a shared mental model for sustainable development. It is based on four overarching principles or system conditions to define the favorable outcome of sustainability. The system conditions are the following:

I. Substances from the Earth's crust must not systematically increase in the ecosphere.

II. Substances produced by society must not systematically increase in the ecosphere.

III. The physical basis for productivity and diversity of nature must not be systematically diminished.

IV. Resources must be used fairly and efficiently to meet basic human needs worldwide.

The first three system conditions of the Natural Step are constituted from three basic mechanisms, which can destroy natural capital. To invert the negative outcome, the system conditions are described by adding a “not”. The fourth condition constitutes the social aspect in terms of human needs. Future-Fit Business Benchmark (2016) provides a framework for businesses to apply the Natural Step principles.

NATURAL CAPITALISM

Natural Capitalism is an economic framework, which consists of four basic principles and aims to reduce negative human impacts and to re-enter into balance with the carrying capacity of the Earth. The idea is to regenerate and replenish Earth’s resources by taking a whole systems approach which mimics the natural systems of production and consumption. The vision of Natural Capitalism is to establish a *Restorative Economy*. (Hawken et al., 2000, Hawken, 2010)

The principles of Natural Capitalism are the following:

- *Principle 1 is about mimicking biological and ecological processes* (principle of consistency (Paech, 2005)) within industry and consumption patterns (Benyus, 2002). The overall driver of human impact on Earth systems is the destruction of biophysical resources, and especially, the Earth's ecosystems. Hence, a systems perspective and integral management practices are required seeking for holistic solutions that emulate natural systems (Hawken et al., 2000; p. 36). Such perspective and practices would decouple economic growth from the consumption of finite resources leading to resilient economic systems (Birkin, 2001, Ellen Macarthur Foundation, 2013).
- *Principle 2 is named Service and Flow*. It advocates for significantly reducing waste products and using renewable or biodegradable input material free of toxic properties. This paradigm shift is possible by designing systems in a way that they produce no waste or in a way that waste is considered a resource input. Such a system redesign fosters repairing, remanufacturing, reusing, upgrading, recycling and cascading resources for other processes (cyclical production approach) (Ellen Macarthur Foundation, 2013). It also makes waste producers responsible for their waste and transforms products into services (Braungart and McDonough, 2013).
- *Principle 3 focuses on investing in Natural Capital*, namely biodiversity and ecosystem services. This principle assigns economic value in monetary terms to natural capital to take away incentives to overuse and degrade it. By promoting (bio-)diversity, Natural Capitalism builds a fundamental pillar to regain resilience (Robèrt, 2000).

- <u>*Principle 4*</u> *emphasizes increasing resource productivity and efficiency* of material and energy used. Increasing *resource productivity* refers to leveraging or maintaining the utility of a product or process by reducing material and energy demand. And, *resource efficiency* refers to leveraging the quantity of a physical output per input unit. The idea behind principle 4 is that wasteful handling must be traced to detect inefficient and ineffective industrial processes that will need to be updated or replaced to reduce spillover effects (von Weizsäcker et al., 2009).

Any economy following the principles of Natural Capitalism requires redesigning materials, products, processes and business models and implies that toxic chemicals are eliminated, product complexity is reduced and the value creation process of products and services are transparent (WEF, 2014). Companies that participate in this process will form part of the creation of new industries and technologies through innovation.

In 2016, the Natural Capital Coalition (2016) developed a Protocol that guides companies in the process of identifying, measuring, and valuing their impacts and dependencies on natural capital. It can be used to identify risks and opportunities for value creation and as a tool to communicate with stakeholders. This understanding of value creation goes beyond monetary value and includes the importance, worth and usefulness of natural capital for a specific business.

CONCLUSION: BUSINESS OPPORTUNITIES ENABLING THE TRANSITION TOWARDS A SUSTAINABLE ECONOMIC SYSTEM

The system conditions of The Natural Step and the four principles of Natural Capitalism enable the economy to be restorative and regenerative by design. They aim to solve multiple problems at once by removing the underlying root causes rather than “fixing” singular problems once they have occurred (Robèrt, 2000). Such a system provides multiple economic benefits (WEF, 2014b) including the following:

- It reduces the exposure to risks, most notably higher resource prices and supply disruptions; and it increases resilience to shocks and enduring stress.
- It serves as a source of innovation and substantial net savings;
- It helps companies regain the license to operate.

An economy in which The Natural Step and Natural Capitalism predominate has passed a process of system transformation and has changed the mental models of the linear economy and unsustainable consumer behavior towards the shared mental model of these system conditions and framework principles. However, the achievements of restorative economy will not be attained by the sole power of the market system. Instead such a transformation requires several types of government interventions (Borel-Saladin and Turok, 2013). This concerns, for example, new institutions, norms, regulations and behavior-based policies, which have to send sound market signals towards sustainable living, enterprises, goods, and services (Pereira, 2012). Particularly indespendable are the economic instruments that increase the commercial viability of sustainable management strategies (von Weizsäcker et al., 2009).

Multiple macro- and microeconomic approaches address the vision for a sustainable economic system. From the macroeconomic perspective, there exist the vision for a steady state economy (Daly, 2008) or a post-growth economy (Paech, 2012). Some macroeconomic concepts are also supported by policy-makers such as the Green Economy (Borel-Saladin and Turok, 2013), the Circular Economy (Ellen Macarthur Foundation, 2013) and the Bio-Economy (OECD, 2009a).

As this thesis focuses on business opportunities based on insects as biological resources, a promising macroeconomic concept would aim to promote sustainable (business) solutions by using bio-based resources. This aim is pursuit by the Bio-Economy. It will, therefore, be the focus of the following section.

2.3 SUSTAINABLE ECONOMIC SYSTEM: THE SUSTAINABLE BIO-ECONOMY

The overall challenge of efficient governments is the supporting of economic growth that leads to job creation. This aim can be achieved through long-term strategies and coherent policies that address multidimensional goals such as economic development, environmental protection, and social equity. Such strategies were adopted in developed countries since the early 1970s. Here, governments have deployed an impressive array of legislative and regulatory compliances for good environmental and social stewardship to be applied in the processes of resources exploitation, production, distribution, and consumption.

Although direct state regulation has shown to be useful in identifying and eliminating damaging practices in business activities, governments have also recognized the need to enhance the commercial viability of innovative solutions to achieve the aforementioned multidimensional goals. To this purpose, some economic frameworks, which hold clear guidelines related to voluntary commitments for sustainable practices in industry and consumption, have shown to be suitable cultivators for high levels of innovation around environmental and social challenges.

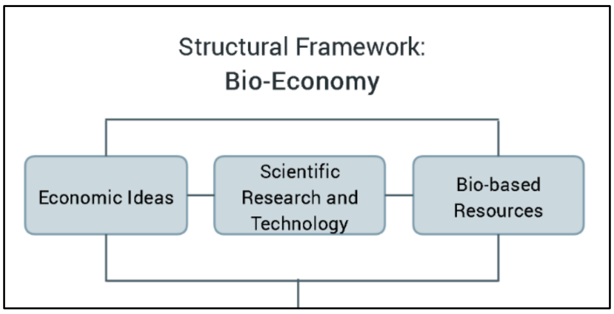

Figure 6: Structural Framework of the Bio-Economy.

The Bio-Economy is such a key example of a ‘*green’* economic framework, which at the same time fits the context of using insects as biological resources as sources for business opportunities. This framework can be positioned in the field of industrial sustainability (OECD, 2001). It “*focuses on sustainable management, sustainable production and the use of renewable biological resources*” (German Presidency to the EU, 2007) to provide innovative and sustainable products, processes and services (BioÖkonomieRat, 2015) (see Figure 6). It envisions the development of a sustainable 'market economy' that combines knowledge from life sciences, biotechnology[3], and renewable bio-based resources to address the great societal challenges. The way it aims to achieve this will be described in the upcoming sections.

2.3.1 ECONOMIC IDEAS

From an economic perspective, the Bio-Economy[4] holds large potential for wealth creation. This potential emerges because the Bio-Economy brings together solid business cases, policy, scientific knowledge and industrial leadership components (Aguilar et al., 2013). In that way, new technology and know-how can develop to create products, services or processes with significant profit margins. Driven by innovation and entrepreneurship through the collaboration of the business sector and academia, it bears huge potential to create employment and incrementally as well as radically transform entire industries. (OECD, 2009a)

The Schumpeterian definition of innovation is clearly applicable to the emerging Bio-Economy as bio-based materials have the potential to break the rules of existing markets and challenge established technological platforms. A major shift originates from the fact that the agricultural sector is increasingly becoming a source of raw materials for industries beyond the traditional fiber and food industries. They include the energy sector, industrial chemical products and health and pharmaceutical products (Golembiewski et al., 2015b). Thus, relatively independent industry sectors are converging (Golembiewski et al., 2015a).

In this process, the farming sector is being transformed from an industry that produces and processes commodity products to one that biologically manufactures specific attribute raw materials for a broader set of end uses (Boehlje and Bröring, 2011). Already today, the primary sector (agriculture, forestry, fishery, food, pulp and paper production) is a key industry where the Bio-Economy is already widely applied and still shows significant potential to further expand applications (OECD, 2009a). In this context, the Bio-Economy combines knowledge from a variety of scientific fields of research (life science, agronomy, ecology, food science and social science) and enabling technologies (biotechnology, nanotechnology, information and communication technologies and engineering) to develop all types of relevant economic activities. (European Commission, 2014)

In 2010, the Bio-Economy-related fields of primary production, health, food processing were producing 1 billion Euros in value added (European Commission, 2012a). By 2025, the European Commission (2012b) expects the Bio-Economy sectors to create 45 billion Euros in value added. Interesting examples relate to environmental remediation, new disease diagnoses, and therapy techniques, and biofuels to propel the economic sustainability (OECD, 2009a).

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[3] Biotechnology can be understood as "the application of science and technology to living organisms […] to alter living or non-living materials for the production of knowledge, goods and services" (OECD, 2013)

[4] A recent policy analysis on the development of the Bio-Economy makes clear that different terms coexist. The OECD for example used the terms 'Biobased Economy' (OECD, 2002)) and Bio-Economy (OECD, 2009) while the German Bioeconomy Council also introduced the term Knowledge Based Bio-Economy. In the context of this work, the writing Bio-Economy is used.

2.3.2 BIO-BASED RESOURCES

As it was already mentioned, the Bio-Economy makes use of biological resources – as opposed to finite resources. The resources are wholly or partly derived from materials of biological origin from the land and sea, as well as biological waste. The waste can stem from a wide variety of industrial sectors excluding materials embedded in geological formations and fossilized materials. Biological waste is used as input in a wide range of industrial closed-loop production cycles that emulate biological processes, mainly from the food and feed sectors, and industrial and energy production.

Those bioprocesses aim to confer three fundamental benefits: First, they aim to facilitate the transition to the growing market potential of biodegradable products– away from toxic materials. Such transition shall help maintain vital ecosystem service. Second, the bioprocesses aim to resolve the problem of the rising costs of fossil fuels and the issue of resource scarcity. And third, they aim to prevent pollution and the emission of greenhouse gases compared to conventional processes. Hence, they strive for reducing land footprints and maintaining atmospheric gas balances, nutrient cycles, and the absorptive capacity of the ecosystems, while providing the economy with the resources needed to function. (Dieckhoff et al., 2015)

All in all, the Bio-Economy promises to reduce environmental impacts and contribute to national environmental goals. In this pursuit, it focuses on environmental management systems in resource productivity and efficiency both onsite and in the supply chain. The latter is mainly steered by control and risk reduction mechanisms, namely health and safety, and environmental regulations. Hence, the Bio-Economy promotes environmental protection through sustainable principles of eco-efficiency and eco-effectiveness.

Further, the sustainability aspect strongly concentrates on the supply side. Here, it focuses on sustainable primary production and processing systems with the ultimate goal to increase resource efficiency and promote renewable resource input. Both shall then lead to a reduction of the environmental impact and greenhouse gas emissions (European Commission, N.N.).

2.3.3 SCIENTIFIC RESEARCH AND TECHNOLOGY

Developing a sustainable Bio-Economy that uses eco-efficient bioprocesses and renewable bioresources is one of the key strategic challenges of the 21st century. Its beginning can be traced back to break-through research on molecular biology in the 1950s and 60s and was enabled by the advancing and in-depth knowledge in the traditional natural sciences fields of biology and chemistry. Finally, it gave the start for a new field of research, namely biotechnology (Aguilar et al., 2013). Biotechnology, together with information technology, nanotechnology, engineering, and communication technology is called *key enabling technologies* which build the fundament of the Bio-Economy. By applying them to biological organisms, products, processes, and systems, (new) profitable and environmentally friendly products can be developed (OECD, 2001; p. 5). Therefore they are considered by researchers and policy-makers as means of achieving sustainable solutions, which hold potential to cope with global challenges, develop technology competitiveness, and create new markets (European Commission, 2014).

Key enabling technologies have been subject to impressive levels of investment to expand research to other disciplines such as agronomy, food science, and social science, to develop new markets and gain wider stakeholder acceptance for its numerous applications. As a result, technological developments and innovations in the Bio-Economy have created new products and applications. Those encompass the development and production of biological pharmaceuticals, bioplastics and composite materials, second and third generation biofuels, bio-based chemicals, cosmetics and high-value foods. It further relates to the manufacturing and capital goods industry. Here, new machinery and equipment are related to Bio-Economy development, for example in the area of medical equipment and the construction of chemical plants. Additionally, in the services sector, innovations are achieved by the application of biological knowledge, such as in environmental engineering, bioprospection, bioinformatics or biomimetics. An extended overview can be found below:

- Primary Sector: Deliberate selection of high-yielding crops and livestock to make them more resistant to pests, water scarcity, and diseases and grow faster. In this way, the increasing demand for resources can be satisfied.
- Across Industries: Use of living organisms such as microorganisms or plants as biosensors and bioremediation; thereby contaminated soil or water can be detected and/or cleaned up. This can enable regeneration of degraded areas.
- Health Industry: Application of fundamental science to biological organisms to develop new health diagnoses and therapy techniques; e.g., for the development of new-generation antibiotics, HIV, and cancer cures.

The examples show that Bio-Economy solutions leapfrog current solutions which is the reason Fund et al. (2015; p. 7) state that "it is important to differentiate the Bio-Economy from traditional primary production in agriculture, forestry, and fishery. The Bio-Economy uses new scientific knowledge and emerging technologies for the development of bio-based processes and the transformation of natural resources into sustainable products and services."

It is because of the potentials described above that the International Advisory Committee of the Bio-Economy[5] (accronym: IAC, 2015; p. 4) praised the opportunity to develop solutions to the global challenges. In particular, it identified eight out of 17 Sustainable Development Goals (SDG) that could be addressed in the Bio-Economy. Those SDGs are: food security and nutrition (goal 2), healthy lives (goal 3), water and sanitation (goal 6), affordable and clean energy (goal 7), sustainable consumption and production (goal 12), climate change (goal 13), oceans, seas, marine resources (goal 14), and terrestrial ecosystems, forests, desertification, land degradation, and biodiversity (goal 15).

[5] The IAC is a "community of experts and stakeholders from more than 50 countries [who] met in Berlin to review the state of Bio-Economy in different parts of the world and to identify opportunities for accelerated transition towards a more bio-based Economy" (IAC, 2015; p. 4)

2.3.4 DIRECTIONAL RISKS IN THE BIO-ECONOMY

Nonetheless, the globally developing Bio-Economy is anything but homogenous as was shown in a policy analysis of 45 national Bio-Economy policy strategies. This analysis also raises awareness that the Bio-Economy is not inherently sustainable (Fund et al., 2015). It found that even though most strategies have been worked out to respond to the societal challenges, they are also aiming to achieve partly conflicting goals. Hence, the sustainability intention of business models resulting from the Bio-Economy does not necessarily lead to the desired sustainable impact. Instead, in some cases, they may even lead to solutions that clearly contradict those sustainability principles in which they are inspired.

Further, the development of the Bio-Economy and the multifunctional use of bio-based materials in a growing number of industries and sectors have intensified the discussion of the complementary or competitive nature of the economic motivation of creating value and the social motivation of environmental responsiveness and sustainability (Boehlje and Bröring, 2011). In fact, the policy concept has received broad criticism against multiple concerns fearing security risks originating from the application of biotechnology, also known as *biosecurity*. The following list addresses some of the social and environmental concerns (Sheppard et al., 2011):

- Engineered genes, also known as novel crops and genetically modified organisms, can lead to unknown allergies and can have toxicity-associated impact on humans.
- Mismanagement of trail plantations can lead to the abandonment of trial areas without removing the plantations when recognizing that the plantations are not suited for the market. Those crops can then invade traditional plantations and natural landscapes. (Delvenne and Hendrickx, 2013)
- Through the introduction of genetically modified organisms, new kinds of pests and weeds can emerge or those aimed to be fought become more resistant (Cerritos Flores and Cano-Santana, 2008).

Apart from these concerns, the Bio-Economy also comes with considerable socio-economic risks for farmers due to the technologization of bio-based materials. As stated in the OECD-report on the Bio-Economy (2009a), already today farmers in developing countries suffer from great economic losses because they cannot afford plant protection products– be it the seeds, the fertilizers or pesticides.

Hence, the technologization - which might make sense in the consumerist economies where there is great wealth - increases dependency in the bottom of the pyramid economies where people live in fiercest poverty lacking minimum standards (Boons and Lüdeke-Freund, 2013). This further fuels the problem of inequality as well as the problem of resource-driven conflict. The impact is particularly severe in the agricultural sector, where 70 percent of the global population works and upon which 100 percent of the population is dependent.

Thus, those negative effects should set researchers and practitioners into alertness and remind policymakers that a new economic model striving for sustainability needs a careful analysis of risks associated to sustainable innovations to avoid ambivalences that lead to unsustainable behavior. Clearly, from a sustainability perspective, the potentials of the Bio-Economy should not only consider solutions related to scientific knowledge and emerging technologies, but also those emerging from the traditional primary production in agriculture, forestry and fishery.

A popular approach showing the way the same concept can be applied to the low-tech and knowledge-based Bio-Economy is *cascading*. It refers to using biomass for a material first before recovering its energy content at its end-of-life (Pauli, 2012). Consequently, it goes beyond merely multiplying the traditional way of producing and consuming biomass and includes its regeneration. As part of the Bio-Economy, biorefineries use cascading, focusing in particular on organic waste reuse. Hence, applying the approach of cascading could be a step towards a more sustainable Bio-Economy. (O'Brien et al., 2015)

Furthermore, to overcome polemics, efficient and transparent sustainable management is required. It should acknowledge equal importance for society, the environment, and economic returns. The acknowledgment implies that instead of focusing on the technological level of solution finding, it is vital to promote clear criteria, principles, and guidelines to ensure directional certainty. They can be used to develop directives and a shared vision for a sustainable economy. Moreover, innovation development paths are needed to achieve alternative sustainable solutions. In this attempt, business models can be used as ideal tools to depict business opportunities.

2.3.5 NEED FOR A SUSTAINABLE BIO-ECONOMY

So far, this section gave a general overview of the Bio-Economy as a political and economic framework. As it was defined, it can be taken as a matter of fact that it tends to privilege win-win situations through eco-efficiency and eco-effectiveness. In this pursuit, it builds on solid business cases supported by biotechnologies and scientific know-how in the domain of life sciences to create value added on biological resources.

Because of the risks that Bio-Economy-related activities entail, the International Advisory Committee advocates for a 'Sustainable Bio-Economy' – a Bio-Economy which solves global challenges by enabling the progress of decoupling economic development from natural resource use and sustainability of its footprint. Such a Sustainable Bio-Economy will require becoming competitive under the consideration of the costs of negative externalities (IAC, 2015). This means that the attained environmental savings or burden relief effects outweigh the 'investment' of resources, energy, or other ecological costs incurred by the introduction of the innovation (cf. Paech, 2007).

Only by using new mental models can this vision be achieved. The scientific, political and business community has to adopt the triple bottom line mindset in order to design solutions of the Bio-Economy (Elkington, 1999, OECD, 2001), which actively seek for a social and natural case in addition to the economic case (Dyllick and Hockerts, 2002).

While the *natural case* seeks to increase and maintain bio-based value through eco-effectiveness and sufficiency, the *social case* promotes social well-being through ecological equity and socio-effectiveness. Hence, the Bio-Economy should provide solutions for managing resources in a responsible, inclusive and effective manner. In that way, it should reduce land footprints over the production, distribution and consumption cycles while keeping in mind the potential tradeoffs of the sustainability efforts.

Providing sustainable solutions is one condition for paving the transition towards a sustainable economy, understanding them as a business opportunity is the second condition, and building a sustainable business out of it is the third condition. The following section elaborates on these conditions.

2.4 BUSINESS OPPORTUNITIES IN THE FRAMEWORK OF SUSTAINABLE ENTREPRENEURSHIP

The transition towards a resilient society and a sustainable economic system – such as a Sustainable Bio-Economy - can be considered to be the primary challenge of the 21st century (Meadows et al., 2004). It will require radical shifts in lifestyles and the way goods and services are designed, produced and used. To make those far-reaching shifts, the status quo demands a profound rethinking – a process that needs entrepreneurial spirit and disruptive innovation.

Bringing about innovative solutions calls for the ability of opportunity recognition and its exploitation (Shane and Venkataraman, 2000). Theoretically, this could be done by individuals (entrepreneurs) and by several societal groups, namely civil society, governments, and incumbents. However, for instance, the pursuit of sustainable measures within incumbents, namely corporate social responsibility, is more concerned with doing less bad than doing good. It has shown to be useful in identifying and eliminating damaging practices to arrive at additional resource efficiency both onsite and in the supply chain (von Weizsäcker et al., 2009; p. 281), but falls short of establishing game-changing approaches. Therefore, by looking at the outcomes regarding sustainable development, it can be concluded that the achievements of the social groups are falling far short of the required levels of transformation.

Game-changing approaches, however, are more likely to originate from entrepreneurs. Those are individuals, teams and novo start-ups who are concerned with the discovery, creation, and exploitation of profitable opportunities (Binder and Belz, 2015). Hence, through entrepreneurship - the process of opportunity discovery, creation, and exploitation - entrepreneurs produce market-oriented innovations, which can result in novel products, services, technologies, processes, and business models (Nidumolu et al., 2009). Therefore, entrepreneurship and innovation are two inseparably linked concepts.

Whether an opportunity is attractive to entrepreneurs or not, depends on their *mental models* (Gartner et al., 2008). Mental models refer to the entrepreneurs' beliefs, personal experiences, expertise, skills, goals, demographics, and judgments regarding the attractiveness of opportunities. Thus, not all entrepreneurs are tuned to perceive opportunities for sustainable development. For that reason, the research focus lies on entrepreneurship that strives for a nexus between sustainable development and business opportunities, namely *sustainable entrepreneurship*. Fichter and Tiemann (2018) define sustainable entrepreneurship as “as the discovery, creation, evaluation, and exploitation of opportunities to create innovative goods and services that are consistent with Sustainable Development Goals.”

In the following subsections, the field of sustainable entrepreneurship is positioned in the context of entrepreneurship and distinguished from other related concepts. Furthermore, the mental models of sustainable entrepreneurs are addressed in more detail. Once those aspects are thoroughly elaborated, sustainable entrepreneurship is related to business opportunities. After this concept is defined and distinguished from sustainable business opportunities, dimensions and features of business opportunities are depicted. Furthermore, challenges and requirements for realizing sustainable business opportunities are addressed. Finally, as this project aims to assess sustainable business opportunities, dimensions need to be identified to do so. This is subject to the last part of this section.

2.4.1 DELIMITATION OF SUSTAINABLE ENTREPRENEURSHIP FROM RELATED CONCEPTS

Sustainable entrepreneurship is a nascent research field which received in-depth attention by Thompson et al. (2011) and Binder and Belz (2015). It originates from traditional entrepreneurship and shares commonalities with social and environmental entrepreneurship. Its origin and related concepts will be delineated in the upcoming paragraphs (see Figure 7).

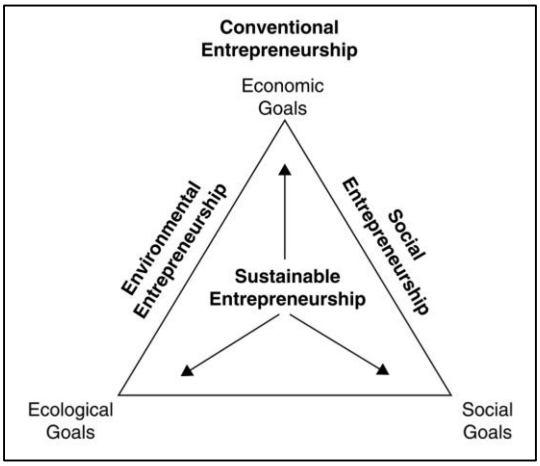

Figure 7: Sustainable Entrepreneurship and Related Concepts
Source: Binder and Belz (2015)

Traditional entrepreneurship pursues single bottom line goals because it mainly focuses on the financial rewards, profit maximization, cost reduction and outcome maximization (Schumpeter, 1947a, Parrish, 2010). Even though this is an oversimplification of reality and every type of entrepreneur has multiple motivations, and drivers for its activities (Cohen et al., 2008), the social and environmental entrepreneurship go beyond pecuniary self-interest and strive for an extended societal value creation.

Social entrepreneurship is characterized by a strong drive of altruism and willingness of the entrepreneur to address societal illnesses. It can take place in for-profit and non-profit organization, thus for a subset of social entrepreneurs, the profit motive is not absolutely necessary. Instead, social entrepreneurship places primacy on their social mission, namely helping people in the form of products and services. Consequently, the main value creation of social entrepreneurship is only one of three aspects of sustainable value creation. (Thompson et al., 2011)

Environmental entrepreneurship or ecopreneurship is the simultaneous creation of economic and ecological profit by addressing environmentally relevant market failures. Its motivations are likely to be mixed, with a blend of environmental and economic ideology. Hence, it can be said that environmental entrepreneurship–which is also recognized as green entrepreneurship and ecopreneurship--agrees that a double bottom line of environmentally responsible and yet profitable opportunities is at the core of the concept (Binder and Belz, 2015).

Sustainable entrepreneurship goes beyond those one and two-dimensional goals and strives for a tripartite purpose. This is because the roots of the term stem from the concept of sustainable development (Binder and Belz, 2015), and therefore economic, social and environmental goals are equally important. Its role focuses on influencing the entire market, which in turn influences society as a whole (Schaltegger and Wagner, 2010). Thus, sustainable entrepreneurship is clearly associated with the promise of more traditional concepts of entrepreneurship but also brings additional potential both for society and the environment (Kuckertz and Wagner, 2010).

Due to the orientation on sustainable development and because this thesis is looking for an impetus for the transition towards a sustainable society, it will focus on sustainable entrepreneurship. This term can also be seen in other contexts, for example as social movements, environmental grassroots or social concern movements (Schaltegger and Wagner, 2010). However, I will set it in the context of market-oriented practices for sustainable development in which entrepreneurs are viewed as actors who strive for growth by enlarging companies and expanding businesses and which have the potential to transform industries, institutions and societies.

2.4.2 MENTAL MODELS OF SUSTAINABLE ENTREPRENEURS

Researchers such as Patzelt and Shepherd (2011; p. 632) and Parrish (2010) have found that sustainability-oriented entrepreneurs are strongly influenced by knowledge of the natural environment, by underlying *drivers*, *principles*, *values* (e.g., personal motivation, altruism and awareness for environmental and community issues) and *personal experiences* (e.g., threat of a declining environmental and/or community quality) that make them aware for sustainability.

Moreover, they ideally possess the prior entrepreneurial knowledge and practical expertise as a necessary precondition of entrepreneurship (Parrish, 2010, Bergset and Fichter, 2015). Furthermore, it is often situational cues that awake the inner entrepreneur within people (Shane and Venkataraman, 2000) who then recognize business opportunities, and eventually exploit them (Schumpeter, 1947a). For an overview of this process see Figure 8.

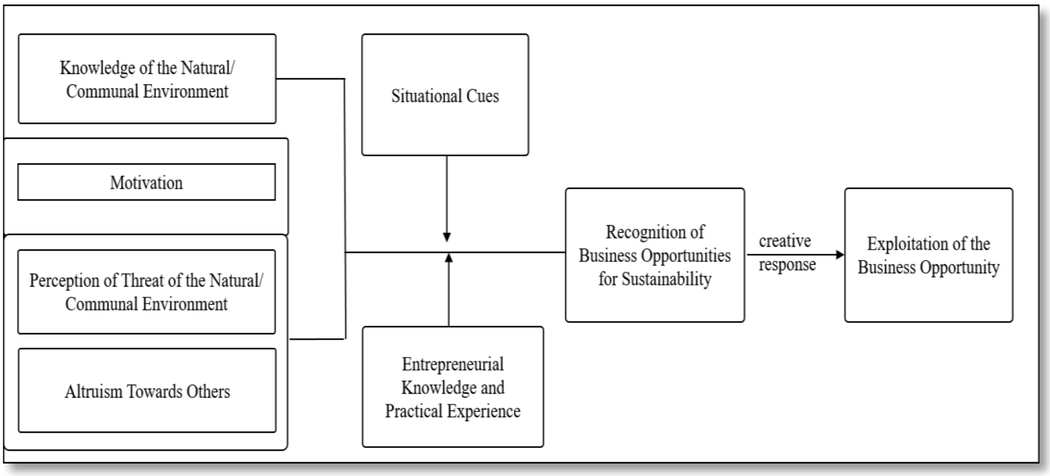

Figure 8: Mental Models of Sustainable Entrepreneurs for Opportunity Recognition
Source: The model originates from Patzelt and Shepherd (2011; p. 632) and is complemented by information from (Schumpeter, 1947b), (Shane and Venkataraman, 2000) and (Parrish, 2010).

The aforementioned values, principles and drivers incentivize sustainable entrepreneurs to link sustainability performance with the economic success of their company, in a way that they view their "enterprise [] as a means of perpetuating resources, with the underlying logic of using human and natural resources in a way that enhances and maintains the quality of their functioning for the longest time possible."(Parrish, 2010; p. 511).

2.4.3 (SUSTAINABLE) BUSINESS OPPORTUNITIES: DEFINITION AND SOURCES

Shane and Venkataraman (2000; p. 220) define business opportunities or entrepreneurial opportunities as "those situations in which new goods, services, raw materials, and organizing methods can be introduced and sold at greater than their cost of production." The business models can be added to this definition. They are tools that describe how to create and commercialize value and are central to this thesis.

Furthermore, as this work is set in the context of sustainable development, the aim is to identify and assess *sustainable business opportunities*. Patzelt and Shepherd (2011; p.632) refer to such opportunities as "opportunities that sustain the natural and communal environment as well as provide development gain for others." Setting this definition in the context of the Sustainable Development Goals, this thesis refers to *sustainable business opportunities as situations in which new goods, services, raw materials, business models and organizing methods can be introduced and sold at greater than their cost of production and which are consistent with the Sustainable Development Goals* (cf. definition of sustainable entrepreneurship by Fichter and Tiemann, 2018).

Business opportunities can be created or discovered. While *opportunity discovery* occurs within existing economic structures, *opportunity creation* requires the development of new economic institutions, namely governmental legislation, patents and industry norms (Pacheco et al., 2010) as well as educating consumers and priming them for market adoption. In the context of the pursuit of transition towards a sustainable economy, the process of *opportunity creation* is of particular importance, because in this way, sustainable future goods and services can be created that hold the potential to lead to such a transition.

DIMENSIONS AND FEATURES OF BUSINESS OPPORTUNITIES

Business opportunities can be clustered according to their (1) *Locus of Change*, (2) the *Initiator of Change*, (3) *Sources of Business Opportunities* and (4) *Influencing Factors* (see Figure 9).

LOCI OF CHANGE

Loci of change (1a) can be the creation of new products or services, (1b) loci that originate from the discovery of new geographical markets, (1c) change that emerges from the creation or discovery of new raw materials, (1d) changes that emerge from new methods of production, and (1e) those that are generated from new ways of organizing (see Figure 9) (Eckhardt and Shane, 2003).

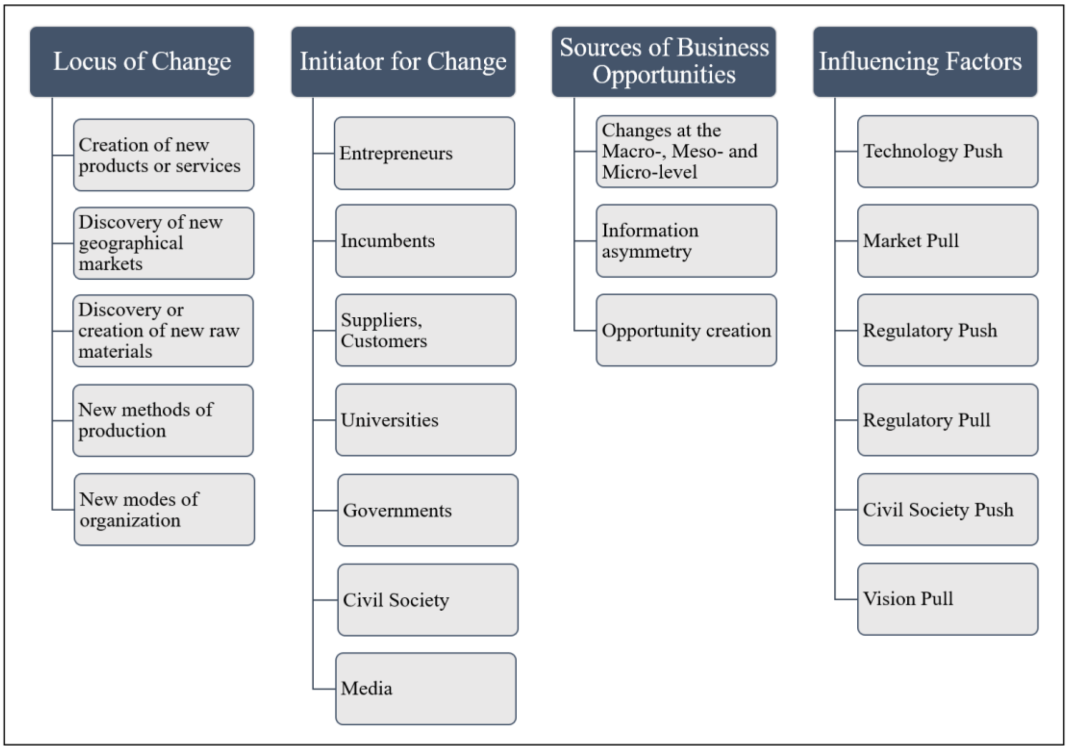

Figure 9: Dimensions and Features of Business Opportunities
Source: Chart based on (Eckhardt and Shane, 2003, Fichter, 2005b, WBGU, 2011).

INITIATORS OF CHANGE

The initiators of change (1) can be commercial and non-commercial entities. Commercial entities are, among others, entrepreneurs, incumbents, suppliers, and customers. Non-commercial entities are universities, governments, and non-governmental organizations. This thesis sets particular emphasis on the role of the sustainable entrepreneur as a key change-maker for a transition towards a sustainable Bio-Economy.

SOURCES OF OPPORTUNITY

The third type of opportunity refers to the sources of opportunities (3). Those result principally from (3a) changes at the macro-, meso- and micro-level, from (3b) asymmetries in existing information between market participants, and from (3c) opportunity creation. Those three subtypes are explained further in the following subsections.

Macro-Level, Meso-Level and Micro-Level

The WBGU (2011)[6] differentiates between three levels of change: The macro-level, the meso-level and the micro-level. Each of these levels can bring about business opportunities.

[6] WBGU refers to the Scientific Advisory Council of the Federal Government of Germany about Global Environmental Change.

Changes at the macro-level can be gradual, long-term and ad hoc. Global challenges such as climate change, population growth, and pollutions are an example of gradual, long-term changes. Ad hoc changes can, for example, be produced by natural disasters which can produce significant consequences. An example is the disaster in Fukushima, which led to the political decision in Germany to initiate the energy transition towards renewables (Energiewende).

At the meso-level, policy instruments and economic frameworks can be mentioned as sources of opportunity. In the context of this thesis, the Bio-Economy presents such a policy framework. Here, opportunities are created by combining (1) economic ideas with (2) scientific research and technology and by using (3) novel materials stemming from bio-based resources (see again Figure 6). It combines fundamental elements to create new sources of opportunities.

At the micro-level, it is niches and pioneers of change that create new sources of opportunities. Such change agents can be sustainably-oriented entrepreneurs, scientists, members of non-governmental organizations (NGOs), journalists or pioneers of change in ministries and international organizations. It is important that the pioneers reach a certain degree of awareness by the wider society. Otherwise, the opportunities created by them will be weak and remain widely unrecognized.

All in all, these three levels interact and influence each other. Therefore, changes in one level may produce a change in the other levels.

Information Asymmetry

The second source of opportunities is asymmetric information. Asymmetric information exists when one party of an economic transaction possesses greater material knowledge than the other party. Such asymmetries can occur at the macro- and microeconomic level. It can occur during a transaction between a seller and buyer (Godley, 2013) as well as when people make an assumption about an industry, which does not fit the reality.

A great wealth of business opportunities can be detected through the lens of sustainability. The global challenges, the Sustainable Development Goals or the planetary boundary concept can serve as compasses to make the true cost of a product or resource transparent and thus help detect market inefficiencies (Cohen and Winn, 2007, Hall et al., 2010). Additionally, the application of conceptual frameworks for sustainability, such as The Natural Step or Natural Capitalism, can serve as a compass to develop sustainable solutions.

Opportunity Creation

While entrepreneurs may develop their business ideas based on external stimuli such as from changes resulting from technology, customer preferences, the discovery of new resources (e.g., biological resources) and economic institutions (e.g., governmental legislation, industry norms, regulations and behavior-based policies), they can also create their own opportunities. Entrepreneurs can untap markets by developing new economic institutions as well as educating consumers and priming them for market adoption.

The process of influencing policy instruments is known as *institutional entrepreneurship*. Shepherd and Patzelt (2011; p.148) define an *institutional entrepreneur* as an "actor that has an interest in developing new institutions or facilitating change in existing institutions and leverages resource to achieve change." It can be expected that this role is often adopted by sustainable entrepreneurs, as they tend to face incentive problems and legal hurdles. For that reason, Pacheco et al. (2010; p. 417) estimate that "given the magnitude of incentive problems in our current economic system, [new economic institutions] may represent the greatest source of sustainable entrepreneurial opportunity and the greatest potential to create value through more sustainable business models."

INFLUENCING FACTORS

Business opportunities can also be identified from the angle of exogenous influencing factors sustainable innovations. Fichter (2005a; p. 131-133) identified six basic factors shortly addressed in the following list:

- *Technology Push*: A central element of business opportunities is new technology which is driven by new knowledge. In the Bioeconomy, new knowledge and the use of enabling technologies (e.g., biotechnology, and nanotechnology) lead to the creation of new information. Combining both with economic ideas will serve to develop all kinds of relevant economic activities related to the invention, development, production, and use of biological materials and processes.
- *Market Pull*: This term summarizes all changes in demand that prompt a company to innovate. Examples for market pull include the decline in demand for a particular product, worsening cost competition with declining profit margins, and changing environmental and health-related customer requirements.
- *Regulatory Push*: Refers to all state and supra-state regulations which set direct incentives for innovation. Such incentives are created through government support and research programs, which provide incentives for market actors to develop or introduce new technologies or product use systems.
- *Regulatory Pull*: It refers indirect state incentives to create innovation. Indirect incentives are created when legal regulations create an indirect impulse to change but also through political debate, and the announcement of regulations. The recent debate about the prohibition of diesel cars drastically reducing sales of these cars is an example of such an impulse.
- *Civil Society Push*: Pressure from civil society can play a significant role in initiating and implementing sustainability innovations in specific sectors and situations. Environmental, human rights or consumer protection organizations as well as scientific institutions, in interaction with the media, can make a huge impact on innovation by publicly scandalizing substances, processes or products. The numerous petitions against neonicotinoids that are predominant active compounds in agricultural pesticides are examples of activities by civil society resonating in the wider society.
- *Vision Pull*: The factor refers to company-wide visions, mission statements, scenarios, strategies or principles of action that stimulate the actors in the value chain to initiate innovation initiatives or significantly influence the direction of innovation. The vision of avoiding palm oil in products such as cosmetics and food is an

example of the way consumer product producers put pressure on their suppliers to change the supply of raw materials.

CONCLUSION

In this section, numerous dimensions and features of business opportunities were identified. The abstract knowledge about them will be helpful to identify business opportunities in the Insect Economy. For further detail about business opportunities see page 58 (research question 1).

2.4.4 SUSTAINABLE BUSINESS OPPORTUNITIES: CHALLENGES AND REQUIREMENTS FOR SUCCESS

Discovering or creating business opportunities is only the first step in a long endeavor to realizing concrete solutions. The process of idea realization or opportunity exploitation is challenging: It requires entrepreneurs to commit substantial amounts of resources (e.g., regarding time, attention, financial investments, social capital). Furthermore, they need to evaluate whether it is worthwhile the effort to exploit the opportunity; and on a constant basis, they need to make decisions. Such decisions include making strategic changes, switching to an alternative opportunity and to even abandon the entrepreneurial attempt altogether. Thus it is not clear from the beginning, which course the exploitation of a business opportunity will take. For that reason, entrepreneurs have to accept a high degree of uncertainty and ambiguity (Gruber et al., 2015).

In addition to the common challenges of entrepreneurship, specifically *sustainable entrepreneurs* have to reconcile conventional business imperatives with their pursuit of triple bottom line solutions. Those imperatives include that businesses strive to mitigate costs and reduce uncertainty, improve product availability and, more importantly, attain room to scale for growth. The described imperatives often lead to a narrow view by which the transfer price in the marketplace is the most focused detail.

The transfer price is determined, on the one hand, by the costs and, on the other hand, by the customers' value perception of the products and its purchasing power (customers' willingness to pay). There are powerful instruments to influence this perception but, in the end, the only place to exert some useful effort is on the cost side. To keep costs low, companies are primarily guided by efficiency principles, balanced with different sets of standards about health and safety, and environmental regulation.

To be successful in mainstream markets, sustainable entrepreneurs have to develop superior products or processes at competitive prices. A way to achieve that is by adopting a strategic approach, which guarantees economic success by strengthening the links between monetary and sustainable (non-monetary) activities. Such a strategic approach poses a *business case for sustainability*.

It is the target and purpose of a business case for sustainability to achieve the integration of both economic sustainability as well as social and environmental sustainability equally. In the first place, "a business case for a sustainability innovation implies the existence of a sufficiently high willingness to pay (WTP) in the relevant market that enables the product or process innovation in question" (Schaltegger and Wagner, 2010; p. 10). Furthermore, it has to be supported by solid *business drivers (for sustainability)*.

Business drivers are variables that directly or indirectly influence economic success (Schaltegger et al., 2012). Core business drivers for sustainability are, e.g.,

1. The potential to grow by enabling better access to certain markets and access to new markets.
2. First-mover advantages that foster innovation.
3. Increased reputation and legitimacy.
4. Risk reduction, long-term orientation, lower cost of capital and labor costs (see a.o. Hart and Milstein, 2003, Orlitzky et al., 2003, IBM Global Business Services, 2011, Schaltegger et al., 2012, Sommer, 2012).
5. More indirect effects through social activities involve non-market links and actors such as initiatives and civil society.
6. From a broader economic perspective, it can lead to potentially sustainable solutions and new job creation.

Indeed a longitudinal study with data of over three decades has shown that sustainability-orientation in business leads to clear financial benefits for companies (McWilliams and Siegel, 2000). Moreover, because the list of arguments in favor of sustainable business solutions is so extensive, Nidumolu et al. (2009) and Hall et al. (2010) argue that sustainability holds the potential both to create competitive advantage and be a starting point for a transition towards a sustainable economy.

2.4.5 DIMENSIONS FOR ASSESSING SUSTAINABLE BUSINESS OPPORTUNITIES

To answer the research questions, the concept of 'business opportunities' plays a central role. While in research question (1), the aim is to *explore, describe and characterize* emergent business opportunities around insects as biological resources, in research question (2), the aim is to *assess and classify* sustainable business opportunities based on insects.

Business opportunities were earlier identified as *situations* in which *new goods, services, and raw materials, and organizing methods* can be introduced and sold at a price that is greater than their production costs (see page 35). Thus, the exploration for business opportunities based on insects will focus on *goods, services, and raw materials, and organizing methods* based on insects and is therefore tangible.

However, to be able to do the assessment and classification of the identified opportunities (research question 2), it is necessary to define dimensions. These dimensions need to be practice-oriented and ideally tangible because the basis for the assessment is interviews with entrepreneurs who are exploiting business opportunities based on insects.

A first approach to assess sustainable business opportunities is evaluating them through a *business model.* It is a tool that articulates the business logic of a venture and captures economic value while delivering social and environmental benefits (Osterwalder and Pigneur, 2010). It is a commonly used tool by entrepreneurs and can, therefore, be used for interview questions (see page 46). There will be different sustainability effects depending on the specific business model. Thus, entrepreneurs can be asked about their motivations to engage with either one or another solution (see page 46). Using this approach only allows for a soft assessment. It, however, gives the first idea about the sustainability-orientation in the respective field.

There exist specific associated tools to business models, such as the *Business Model Innovation Grid* that aims to inspire businesses to make their business model more sustainable (see page 48). The grid consists of predefined mechanisms of sustainable solutions and can facilitate not only the assessment, but also the classification of the business opportunities.

The assessment can also take place by adopting the perspective of the *global challenges* and *the Sustainable Development Goals (SDGs)*. In particular, the SDGs were earlier identified as global priorities that are interconnected with business practice (see Figure 4). Therefore, they can be used as a compass to understand the linkage between the contribution of a venture and sustainable development. The advantage of using the SDGs is that they also consist of predefined dimensions - the 17 goals - which is the reason they could also both facilitate the assessment and the classification of the business opportunities.

Such a predefined framework is not provided with the *global challenges* (see page 9), where different termini and numbers of challenges exist (see e.g., Glenn and Florescu, 2015, World Economic Forum, 2015, United Nations, 2016a). Nevertheless, the global challenges are increasingly recognized in business and therefore, valuable for an assessment with entrepreneurs.

Furthermore, business opportunities can be assessed through *business drivers (for sustainability, see page 41)*. They are the factors that spur growth in the areas most important to an enterprise's success. Thus they serve as an indirect assessment of the potential success of a business solution.

Sustainable ventures need to be able to transform (prioritized) sustainability goals into product features that contribute to customer value. This strategic alignment between customer value and the (sustainable) business solution is known as a *business case (for sustainability, see page 40).* Once the business case is weak, the viability of the venture is under threat (Schaltegger et al., 2012, Belz and Binder, 2015).

Business opportunities can also be identified and evaluated by looking at the *risks* that business models entail (see page 50). Risks can, e.g., emerge along the product value chain, can relate to health issues and ethical aspects. Addressing questions about risks can, therefore, be an indicator about the awareness for potential pitfalls that may hamper sustainability.

Ultimately, the attractiveness and viability of business opportunities can also be tested by analyzing the dynamics to which the solution is exposed. These dynamics can be both supporting and hindering the process of exploiting an opportunity. Challenges may include a confrontation with dominant, established competitors, legislation and the compatibility with existing routines with which a business solution may interfere. On the other hand, changes in legislation and consumer demand may foster the idea realization process. The described dynamics are known as *diffusion dynamics* (see page 54).

In summary, sustainable business opportunities can be identified by receiving information about the following eight dimensions:

1. Business Model Building Blocks
2. Business Model Innovation Grid
3. Sustainable Development Goals
4. Global Challenges
5. Sustainability from the Business Case Perspective
6. Sustainable Business Drivers
7. Factors of Diffusion Dynamics.
8. Risk factors

The dimensions: Business Model Building Block, Business Model Innovation Grid, Diffusion Dynamics and Risk factors have received little attention in this thesis so far. They are part of the upcoming section. It contextualizes them in the framework of sustainable innovation and sustainable business models.

2.5 SUSTAINABLE INNOVATION AND SUSTAINABLE BUSINESS MODELS

The central focus of this thesis lies in business opportunities. Those were defined as situations in which new goods, services, raw materials, business models and organizing methods can be introduced and sold at greater than their cost of production (see page 35). When introducing new goods, services, raw materials, business models and organizing methods, then the result is regarded as an *innovation.* In this work, the focus lies on *sustainable innovation – innovation that is consistent with the Sustainable Development Goals*

Such innovations are required to put into practice a fundamentally new logic of doing business on the basis of solving environmental and social sustainability problems and of creating a sustainability transformation of the mass market (Schaltegger et al., 2016). Business model innovations can spur the development of new offerings that contribute to the Sustainable Development Goals.

Implementing sustainable solutions is associated with risks of directional certainty, which can be overcome by orienting on sustainability guiding principles. Besides, diffusion dynamics, which can both enhance and hinder the expansion of innovation in the market, represent important factors to be considered in innovation processes.

In this section the mentioned aspects of innovation are addressed. It is organized as following: At first, the term sustainable innovation is defined and objects of innovation are described. Then, attention is drawn on (sustainable) business models as means to capture economic value and characterize realized business opportunities. After that, more detailed information is provided on directional risks, sustainability guiding principles, and diffusion dynamics of sustainable innovation.

2.5.1 SUSTAINABLE INNOVATION

Innovation can be seen from two perspectives: It can be seen *as a* non-linear, non-constant change *process* (Sosna et al., 2010), which passes through different phases (Scheuing and Johnson, 1989) and *as the result of a process*. This process can bring about all types of novelties such as new technologies, rules and legislation, organizations or even new concepts and ideas. In the context of this thesis, however, innovation is set in the context of business innovation (OECD, 2005) and is understood as "the development and implementation of a radically new or significantly improved product, process or practice which leads to major discontinuities in thinking and acting or in the use of technologies, objects and their performance" (Fichter (2009). Furthermore, this thesis sets a focus on the result of a process and specifically on objects to which the innovation applies.

There exist several expressions to describe the idea of 'novelty' of innovation (Amara et al., 2012). The most categorical differentiation to the degree of innovativeness can be made between incremental and disruptive or market-creating innovations (Christensen and Van Bever, 2014). Incremental innovations relate to efficiency innovations or performance-improving innovations and produce gradual improvements. While they are important and even the most dominant degree of innovation due to short-term returns, it is the market-creating innovations that transform production and consumption patterns.

Sustainable innovation differs from conventional innovation in that it refers to change considering economic, ecological and social aspects with the intention of producing sustainable solutions beyond compensatory innovation. This means that positive private and societal benefits match in a way that no trade-off occurs between both aspirations. To achieve this, sustainable innovation requires more integrated thinking and consideration of several business aspects such as capabilities, stakeholder relationships, leadership and culture. In the context of this work, *sustainable* innovation refers to those innovations that envisage making real and substantial improvements by developing superior production processes, products and services, and by exercising strong market influence and social or political influence (Schaltegger and Wagner, 2010).

In the literature, the meaning of sustainability innovation, sustainable innovation, and sustainability-oriented innovation widely overlap (Bergset and Fichter, 2015).[7] The principal differences in the terms are that the wording "sustainability-oriented" refers

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[7] Bergset and Fichter (2015) conducted a comprehensive literature review on the definition of sustainable innovation and analyzed the difference between those innovation concepts that go beyond profit seeking, namely 'environmental innovation', 'ecoinnovation', 'green innovation', 'sustainability innovation', 'sustainable innovation' and 'sustainability-oriented innovation'. The meanings of these concepts widely overlap. The major difference, however, is that sustainable, sustainability and sustainability-oriented innovations consider economic, ecological and social aspects altogether, while the others primarily focus on economic and environmental benefits, leaving social aspects aside (Schiederig et al., 2012).

to the innovation process while the wording "sustainable" or "sustainability" is focused on the outcome. In the current context, the wording "sustainable innovation" will be used since the focus of this thesis lies in the process result.

Three principal objects of change will be distinguished: (1) products, processes, and technology, and (2) business models. The opportunity to innovate around those objects is identified by the entrepreneur and implemented in the process of entrepreneurship either through the foundation of a start-up or the radical reorientation of an existing organization's business model. In the following subsections, three objects of innovation to bring about novelty are presented.

INNOVATION OBJECT: PRODUCTS, PROCESSES, AND TECHNOLOGY

Many companies still limit themselves to the (technical) dimension of product and process innovation. Incremental innovation mainly refers to these product- and process-related categories of innovation that strongly relate to current production and consumption systems.

INNOVATION OBJECT: BUSINESS MODELS

A business model is a promising tool to describe the business logic of a venture (Bocken et al., 2013, Boons and Lüdeke-Freund, 2013), namely the way it creates and commercializes value and how to manage the underlying logic for value creation (Osterwalder and Pigneur, 2010). Therefore, it can both facilitate and become subject to innovation (Gassmann et al., 2013). A business model can facilitate innovation by serving as a support tool for strategic marketing of innovative processes, products, and services. Moreover, they can become subject to innovation when business models themselves are changed and innovated to provide a competitive advantage by changing the terms of competition and by renewing organizations (Boons and Lüdeke-Freund, 2013, Osterwalder et al., 2014). As business models are a core element to answer the second research question, this concept is described in more detail in the following section.

2.5.2 SUSTAINABLE BUSINESS MODELS AND THE SUSTAINABLE BUSINESS MODEL INNOVATION GRID

In the previous section, business models were introduced as an object of innovation. In this section, the concept of sustainable business models, and specific approaches to business models, namely the ontological and the boundary-spanning approaches are explained. Furthermore, sustainable business model strategies (or archetypes) are presented, which can be used to assess the sustainability of business models. The understanding of these aspects builds the fundament to assess and classify sustainable business opportunities related to insects which corresponds to the second research question.

SUSTAINABLE BUSINESS MODELS: BOUNDARY-SPANNING VS ONTOLOGICAL APPROACH

In the literature, there exists no consensus about what business models are. The only agreement is that value creation is at the heart of any business models, which is typically captured by seizing new business opportunities, new markets and new revenue streams (Bocken et al., 2013). While some authors, cluster business models in an ontological manner (Osterwalder et al., 2005, Chesbrough, 2010, Teece, 2010), others understand them as an activity system (e.g., Casadesus-Masanell and Ricart, 2010, Zott and Amit, 2010, Breuer et al., 2018).

A classical definition of ontological business models is provided by Teece (2010). He states that a "business model articulates the logic and provides data and other evidence

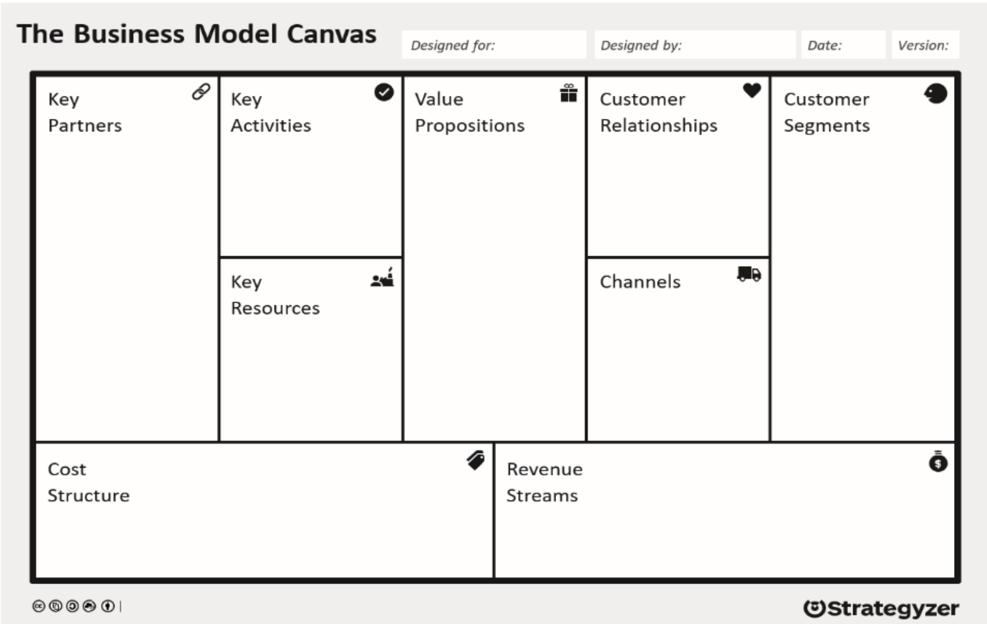

Figure 10: Business Model Canvas
Source: Osterwalder and Pigneur (2010)

that demonstrates how a business creates and delivers value to customers" by breaking down the value creation process into building blocks, namely the profit formulae, the value proposition, and value delivery (sales and communication channels). The benefit of using the ontological approach is that of establishing a shared language and mental model, which facilitates exchanging information on the description, assessment, and change of business models. A widely accepted ontology is the business model canvas promoted by Osterwalder and Pigneur (2010) (see Figure 10).

Adopting the ontological approach to *sustainable* business models, Bocken et al. (2013; p. 484) defines their objective as "to identify solutions that allow firms to capture economic value, thereby establishing a business case for sustainability." The latter enables the creation of measurable ecological and social value in concert with economic value and goes beyond the aim of gaining a 'license to operate.'

Fichter and Tiemann (2015) developed such a Sustainable Business Model Canvas based on the canvas developed by Osterwalder and Pigneur (2010) (see Figure 11). The adaptations contain modifications of building blocks and additional building blocks such as 'vision and mission.'[8] More than that, the canvas is accompanied by an extensive list of questions that relate to each of the building blocks to check whether sustainability aspects are anchored in every building block. The questions address issues of directional risks, and refer to, e.g., the fundamental sustainability guiding principles.

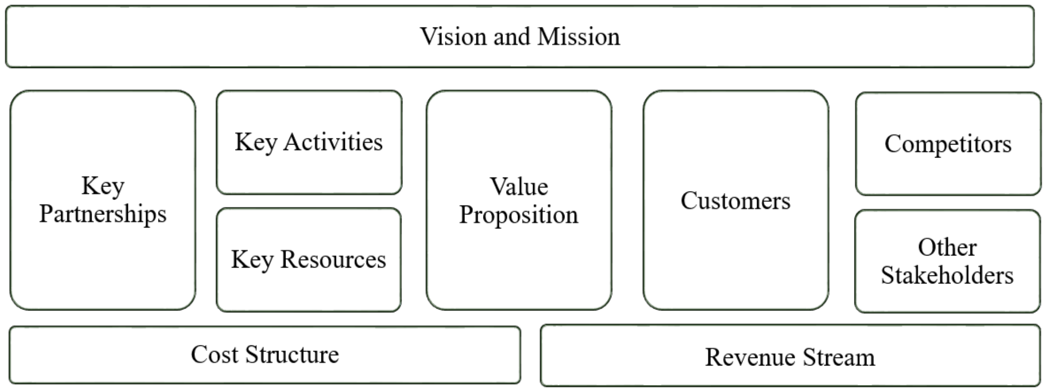

Figure 11: Sustainable Business Model Canvas
Source: Fichter and Tiemann (2015; p. 9)

Thus, the Sustainable Business Model Canvas adopts a comprehensive approach in order to distinguish sustainable business models from conventional ones (Parrish, 2010). Because it adopts a systemic value creation approach, it can be viewed as an enabler for organizational, market and societal transformations. This goes in line with Breuer et al. (2018) call for integrating sustainability-oriented values and norms into business models.

Yet, Breuer et al. (2018) also argue that to extend organizational value creation toward social and ecological value creation, it may be insufficient to simply add new sustainability-oriented elements to the building blocks of conventional profit-oriented business model canvases. Instead, it is necessary to take process-oriented and boundary-spanning approaches to business modeling. Process-oriented and boundary-spanning approaches acknowledge the system dynamics and the embeddedness of all business activities within society.

Zott and Amit (2010; p. 216) propose such an approach and see business models "as a system of interdependent activities that transcends the focal firm and spans its boundaries." Hence, business models allow understanding what, how and who performs the activities which they estimate key to comprehending the functioning of a business. By adopting this view, business models also enable greater flexibility during the innovation process to respond to potential or other risks of directional certainty (Casadesus-Masanell and Ricart, 2010).

In the context of this thesis, an approach is needed that is useful to analyze currently recognized and exploited business opportunities and which is simple enough to analyze multiple business models. The ontological approach is most practical for this

[8] Modifications refer to the building block 'customer' which bundles customer relations, customer segment and customer channels. The new elements are the 'vision and mission', 'competitors' and 'other stakeholders.'

purpose. Furthermore, the questionnaire developed by Fichter and Tiemann (2015) will serve as a suitable guideline for the interview questions.

THE BUSINESS MODEL INNOVATION GRID

The Sustainable Business Model Canvas presented above is one starting point for sustainable innovation. This tool can further be complemented by other solution approaches. Such an approach can consist of identifying sustainable business model innovation strategies. They are groupings of mechanisms and solutions by which sustainable innovation approaches are collated and can be applied in the process of business modeling for sustainability.

Such strategies have been identified by Clinton and Whisnant (2014) who propose a classification of 5 different categories of strategies, namely that of Base of the Pyramid, Environmental Impact, Social Innovation, Financing Innovation and that of Diverse Impact. In total, they identified and described 20 sustainable business model innovation patterns.

Another approach is derived from Boons and Lüdeke-Freund (2013) who distinguish sustainable business models according to three dimensions: technological, social and organizational. Each dimension adopts a more progressive approach to sustainability. While the technological dimension focuses on the fit between technology characteristics and (new) commercialization approaches, the social dimension adopts an external focus on changing markets by enabling social entrepreneurs to create social value and maximize social profit. Moreover, the organizational dimension aims to shape (internal) business practices towards sustainable development, and thereby, shape culture, structures, and routines of organizations.

Based on these dimensions, Bocken et al. (2014) developed the *Business Model Archetypes* which were renamed in their online version as *Business Model Innovation Grid.* (The online version of the Grid is cited as Centre for Industrial Sustainability (2014). the link for the direct access to the web version is: www.vlaanderen-circulair.be/bmix/.) This Grid consists of eight business model *archetypes* (which in the online version are called *strategies*). Those archetypes or strategies "describe *groupings* of *mechanisms* and *solutions* that might contribute to building up the business model for sustainability".

The *groupings* are what Boons and Lüdeke-Freund (2013) refer to as *dimensions*. These dimensions group the archetypes which cluster mechanisms. The '*mechanisms'* refer to all kinds of approaches contributing to business model innovation for sustainability. They were identified through comprehensive review of academic and grey literature (practice) and synthetized into generic mechanisms. They were selected because they refer to innovations "that generate environmental and/or social benefits in business operations - that is, change the value proposition to the environment and society. This may be either through creating new value or significantly reducing negative impacts on the environment and society" (Bocken et al., 2014; p. 45). Thus, the term *mechanism* stands for *mechanism for sustainable business model innovation*. The generic mechanisms are both explained through a definition and a case study available online. The explanations and case studies are what Bocken et al. (2014) refer to as *'solutions.'*

The overall objective of the *Business Model Archetypes* or *Business Model Innovation Grid* is to inspire businesses to reconceive the way they operate and to become more future-proof. On the one hand, the *archetypes* or *strategies* — and specifically the *mechanisms (for sustainable business model innovation)* — enable sustainable innovation because they may create new development paths or capabilities to innovate.

They are suitable to assess existing business models regarding their sustainability. One indicator of sustainability is that a business model combines multiple mechanisms of multiple archetypes. The second indicator is that it stretches across multiple sustainable strategies or archetypes and the third indicator is that it stretches across more than one dimension. Thus the number and diversity of mechanisms used in a business model are indicators of sustainability.

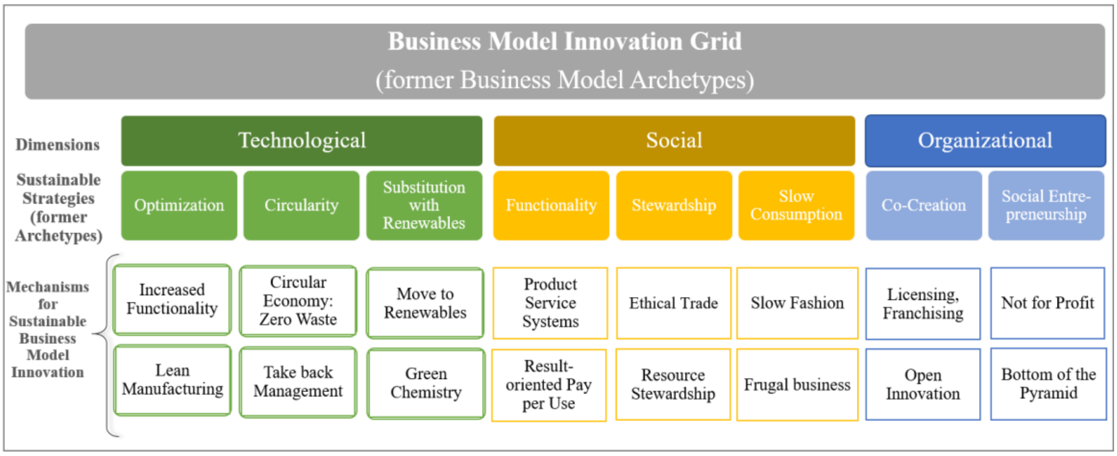

Figure 12: Business Model Innovation Grid
Source: http://vlaanderen-circulair.be/bmix/index.php

The Grid is an evolving tool. According to its online version (www.vlaanderen-circulair.be/bmix/), it consists of three dimensions, eight strategies and of currently 52 mechanisms, which are listed in the Grid as *examples*. It refers to *examples* because Bocken et al. (2014; p. 45) did not intend to provide a comprehensive list of solutions, but to provide "exemplars which explain and communicate business model innovations to businesses in order to de-risk the business model innovation process (e.g., through education and workshops)." Thus, the number of mechanisms is expected to grow further. The Grid is depicted in a simplified version in Figure 12.

The Business Model Innovation Grid will be of relevance for the assessment of the business opportunities based on insects addressed in chapter 4. To avoid confusion due to the two versions of the Grid, hereinafter the following terms are used:

- Instead of *groupings*, the term *dimensions* will be used.
- Instead of *archetypes,* the term *sustainable strategies* will be applied,
- And instead of *examples*, the term *mechanisms for sustainable business model innovation* will be used.

CONCLUSION

In this chapter, two business model approaches were identified: the ontological and the boundary-spanning approach. The ontological approach was identified as convenient to assess realized business models based on insects. To evaluate and classify business opportunities based on insects (research question 2), the model from Osterwalder and Pigneur (2010) will be used as it is already broadly known in research and practice.

Furthermore, both approaches were set in the context of *sustainable* business models. Fichter and Tiemann (2015) developed a questionnaire for business model development which integrates values and principles. Therefore, this questionnaire will be used in the context of the data collection about implemented insect-based business models.

Furthermore, the Business Model Innovation Grid was identified as a complementary tool to the business model canvas to guide companies in evaluating and inspiring their business models regarding sustainability. It was also identified as a suitable indicator to assess the sustainability of business models. For this reason, it will become of relevance for assessing and classifying business opportunities based on insects (research question two).

2.5.3 DIRECTIONAL CERTAINTY OF SUSTAINABLE INNOVATION

Innovation was introduced as a change process. Consequently, it lacks exact prediction and direction. Therefore, to do innovation and seize an opportunity, entrepreneurs have to accept uncertainty and assume a certain level of risks. In the framework of sustainable innovation, uncertainty is not only linked to the marketability of the innovation but also to ecological and social side effects. According to Paech (2007; p. 124-125) “[a]ll new economic activities imply an ecological price, ” and if a new solution falls short of its “envisioned sustainability effect, it automatically becomes part of the problem.” Therefore, striving for directional certainty, namely guaranteeing sustainability as the output of an innovation process (Paech, 2007) leads to new challenges for entrepreneurs and corporate foresight.

There are two distinguished types of potential risks entailed by sustainable innovation: (1) risks whose consequences are recognizable and can be reduced through experience-based precautions and (2) risks which bear a high level of uncertainty with difficulty to predict its possible effects. The risks of ambiguity can be lowered and even avoided by adopting sustainability guiding principles to innovation. Those principles can serve as a checklist during the innovation process as well as a potential source of inspiration (Bergset and Fichter, 2015). However, they will raise the question of the irreconcilableness of scale-up solutions with sustainability. Being a dominant paradigm of business practices, this issue demands an explanation. Therefore, the following subsection will depict the six sustainability principles and discuss the issue of scale. (Paech, 2007)

2.5.4 SUSTAINABILITY GUIDING PRINCIPLES

So far, it was explained that sustainability is subject to the risk of ambiguity. In the pursuit to anticipate this risk, researchers and practitioners are discussing the ways this process can be guided (see, e.g., Robèrt, 2000, Parris and Kates, 2003, Paech, 2007), which business- and product-related aspects need to be considered (see, e.g., Hansen et al., 2009, Bergset and Fichter, 2015, Fichter and Tiemann, 2015), and which tools can be used to promote sustainability within businesses (see, e.g., Benyus, 2002, Bocken et al., 2013, Braungart and McDonough, 2013, Bocken et al., 2014, Tiemann and Fichter, 2014). A shared understanding about the way the risks can be avoided contributes to a common understanding about what constitutes sustainable innovation and sustainable business models and the way they can be designed.

Breuer et al. (2018) contributes to that end in that they identified a set of guiding principles and conceptual elements. In the context of this work, those principles and elements could be used to assess the sustainability of the business opportunities based on insects. In the following subsection, those principles and elements will be presented as *sustainability guiding principles*.

SUSTAINABILITY GUIDING PRINCIPLES

Guiding principles are a series of central “sustainability” characteristics that can be understood as a form of orientation for entrepreneurs and managers to keep track of their sustainability goals. *Principles* reflect normative values behind the business model and tangibly influence the way that model is structured and operates. Therefore, principles hold potential to stimulate a paradigm shift regarding business model development. The following subsections make reference to the following six principles:

- Sustainability-orientation
- Extended value creation
- Systemic thinking
- Stakeholder integration
- Context sensitivity
- Reflecting impacts and outcomes.

SUSTAINABILITY-ORIENTATION

Traditionally, the issue of sustainability refers to establishing inter- and intra-generational equity, and it equally considers the well-being of society, the environment, and businesses (triple bottom line).

Based on this idea, Dyllick and Hockerts (2002) defined six fundamental guiding criteria that strive for the Triple Bottom Line (Elkington, 1999) and can be used for strategic decision-making. These criteria are the following:

- *Socio-* and *eco-efficiency* which focus on win-win situations among economic, social and environmental goals;

- *Eco- and socio-effectiveness* which strives for absolute efficiency;
- *Sufficiency* which is concerned with reducing consumer demand, and
- *Equity* criterion which refers to the fair distribution of rights and responsibilities among people and generations.

Sustainability in business has also become increasingly prominent among mainstream businesses. Conventional businesses, however, primarily adopted incremental and social process innovation (Elkington, 2012). Thereby, they applied sustainable guiding criteria that are mainly limited to *eco-efficiency* and *effectiveness* improvements in production patterns by resource substitution and adaption to natural resource flows (Dyllick and Hockerts, 2002).

Those improvements are commendable but incomplete, as is any strategy that fails to consider the industrial-natural system as a whole (Braungart and McDonough, 2013). The ideal-type of a sustainable entrepreneur (Stubbs and Cocklin, 2008) would strive for a *Net Positive,* which occurs when the positive results of business activities exceed the negative externalities (Forum for the Future et al., 2014). To achieve that, the development and implementation of their business models have to fundamentally base on sustainability guiding principles and on understanding the interrelatedness of the business model components among each other.

EXTENDED VALUE CREATION

It is at the core of sustainable business modeling that the understanding of value generation goes beyond financial terms and includes creating value for society and the environment. This means that other stakeholders than shareholders and customers are considered in the value creation process. In this process, both society and the environment are actively recognized. Bocken et al. (2013) raise attention to the value destroyed and the value missed by neglecting stakeholders that are not directly linked to economic value creation.

This rationale is also adopted by the *shared value* approach. It contends that the negative externalities companies produce impact the company itself even though this impact is not directly reflected in financial figures. Therefore, businesses should analyze the impacts they produce and relate them to their business performance. In response, they should take adequate measures to mitigate or avoid them. (Porter and Kramer, 2006)

SYSTEMIC THINKING

The principles of sustainability-orientation and extended value creation make systemic thinking a mandatory prerequisite to achieving them. In fact, the complexity that globally connected value chains and product lifecycles entail requires thinking in cause-effect chains to bring about sustainable outcomes.

Furthermore, Paech (2007) proposes three basic principles – realms - for a systemic approach to ensure directional certainty. Those realms are:

- Avoiding technological risk that can negatively impact the whole generations
- Adopting flexible solutions and processes that allow innovations to be corrected in case it is required. This is first and foremost an issue of technical changeability such as design characteristics but also requires flexible organizational structures to allow changes to be implemented.
- Creating fit and adaptability which enables continuous adaptation to changes in the context and the circumstances (Tiemann and Fichter, 2014).

Based on them, Paech (2007) recommends limiting sustainable innovation processes to 'experience-based precautions.' Thus, it has to be limited to processes where the risk of ambiguity can be contained through control and safety measures and straightforwardness. This approach, however, poses the question to which extent risks of disruptive future solutions can be anticipated from past experiences.

For those products that contain high risks and are currently used, Robèrt (2000) proposes to increase, at least temporarily, the material flow of certain substitutes that are more environmentally friendly and easier to assimilate in nature's eco-cycles or those that carry lesser 'rucksacks.' In that way, a company can comply with the system conditions of the Natural Step (see section 2.2.2). In the end, however, they should not only be lowered, but phased out altogether (Hawken, 2010).

STAKEHOLDER INTEGRATION

As a logical consequence of the other three principles, sustainable business models have to take into consideration a holistic stakeholder approach. This implies that during the value creation process, broader stakeholder groups such as local communities are taken into account, in addition to customers, suppliers, partners, and employees. Apart from moral and ethical reasons, considering other than economically relevant stakeholders is vital to identify conflicting goals of interests and avoid that social and environmental goals fail to be achieved. Furthermore, stakeholders are important for accessing and acquiring resources and capacities necessary for developing and implementing business models. By taking a network-centric approach, a firm can also reduce negative externalities or value missed (Bocken et al., 2013, Girotra and Netessine, 2013) (Breuer et al., 2018).

CONTEXT SENSITIVITY

Sustainable innovation and business models cannot be assessed in an abstract manner, but their degree of sustainability-orientation depends on a particular business environment and spatial, temporal and cultural contexts (Girotra and Netessine, 2013). Boons and Lüdeke-Freund (2013) emphasize that the demand in consumerist, emerging and Base-Of-the-Pyramid (BOP) economies takes different shapes, and therefore, sustainable innovation will have different meanings and characteristics in different contexts. While in consumerist economies there is great wealth, in Bottom of the Pyramid markets people live in fiercest poverty lacking minimum standards. Hence, while it is a challenge to reduce footprints and decouple production and consumption from negative societal impacts in economies, in BOP markets, it is a challenge to increase human development standards and well-being.

REFLECTING IMPACTS AND OUTCOMES

Due to the risk of ambiguity that sustainable business models entail, it is important to reflect on the impacts and outcomes. The impact should be positive and at least lead to an increase in sustainability, and the outcome should contribute to equity and environmental quality. This means that business conduct should be judged not on a relative scale but on the absolute positive social impact a firm could reasonably have achieved. The realms to ensure directional certainty introduced in the systemic thinking principle (p. 52) can be applied for the first assessment of the overall business impact.

CONCLUSION

From the description of the principles, it became evident that sustainability comes with high complexity. Hence, truly sustainable solutions are necessarily founded on a deliberate process that considers sustainability to achieve the desired result. Even though Fichter and Arnold (2005) and Jay et al. (2016) show that sustainability can somehow emerge incidentally, the risk of ambivalence is very high.

So far, the terms sustainable innovation and sustainable business models are clarified and sustainability principles as guidance to ensure directional certainty are introduced. However, to produce a widespread change, it is important that sustainable business models achieve market penetration. In fact, Fichter and Clausen (2016; p. 2) state that the central problem of sustainable innovations is not their lack of existence "but that their diffusion throughout the economy and society is too narrow and too slow to solve the urgent challenges of sustainability." Consequently, because the impact and outcome of sustainable solutions strongly depend on the process of diffusion, it will be addressed in the following subsection.

2.5.5 FACTORS OF DIFFUSION DYNAMICS OF SUSTAINABLE INNOVATION

Diffusion of innovation describes the "process of imitation and adaptation of an innovation by a growing number of adopters. It comprises the period after the first successful implementation or after market introduction" (Fichter and Clausen, 2016; p. 4). Diffusion traditionally depends on multiple influencing factors: appropriability regimes (e.g., competing industry standards and dominant designs), industry lifecycles and long-term cycles of technological innovation (Kondratiev Cycles). All of them have their inherent logic of temporal unfolding.

Apart from those influencing factors, the process of diffusion of sustainable innovations is somewhat more complicated than non-sustainable innovations. This is on the one hand, because of the double challenge it involves, namely to produce private and wider societal benefits at the same time, and on the other hand, because of the cultural change, it involves, namely the change of current production and consumption patterns. Cultural change is mostly related to radical innovation because current technical and market infrastructures may not be suitable for future sustainable solutions. Furthermore, path dependencies may hinder and slow down the diffusion of radical innovation (Arnold, 2005) (Boons et al., 2013).

Those path dependencies are among others characterized by lock-in effects, inertia and market uncertainty which often slow market acceptance of emerging (sustainable) solutions (Day and Schoenmaker, 2011). Important influencing factors for market acceptance of sustainable innovation are the market power of established providers, governmental push and pull, the influence of pioneers, purchase incentives, compatibility with routines, prices and economic viability and transparency of innovation (see Figure 13).

Market acceptance is most easily achieved with innovations that result in high cost-effectiveness and require only minor behavioral changes. The more, however, the product becomes novel and complex and requires significant behavioral changes because it is incompatible with existing routines of the users, the more reluctant users are in adopting novel solutions. Hence, those solutions that push cultural change are likely to be the most difficult to diffuse. To push such disruptive innovations, government intervention--ideally trough market instruments--is an important factor in making a radical innovation successful. (Fichter and Clausen, 2016)

In conclusion, it is difficult to judge if an innovation earns the title ‘sustainable’ or not due to the lengthy innovation process. This process, however, can be pushed through framework conditions that support the process of imitation and adaptation of sustainable innovations.

2.6 CONCLUSION

Sustainable business opportunities form the basis for introducing innovative and sustainable solutions and those are urgently needed to affront the global challenges and build a resilient society. The process to build a resilient society will require radical shifts both in lifestyles, and the way goods and services are designed, produced and used.

Due to the severity of challenges, these opportunities need to translate into market-creating innovations that are impactful enough to enable large-scale and collective changes in

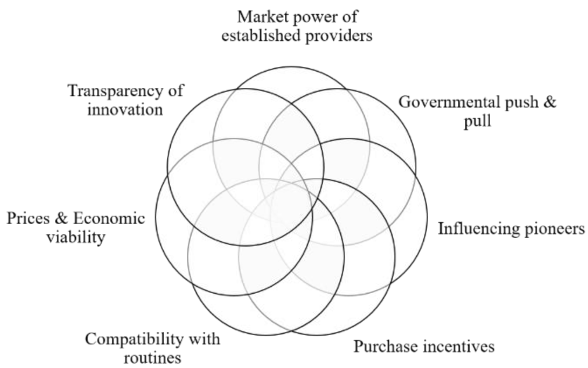

Figure 13: Influencing Factors for Market Acceptance
Source: Own illustration based on Fichter and Clausen (2016)

production and consumption patterns. The Bio-Economy provides a fertile ground for such opportunities to prosper. It creates numerous business cases and is supported by strong business drivers to develop superior products or processes at competitive prices. Business opportunities based on insects as biological resources form part of this set of opportunities and are in focus of this research.

To create sustainable solutions from the opportunities that the Bio-Economy presents, it is not enough to change legislation and innovate around technology. It requires new mental models of businesspeople that actively consider negative externalities of their business practice and are guided by sustainability principles which enable the economy to be just and resilient by design.

Given the urgency to change the current system, a key question emerges: Do business opportunities based on insects present a fertile ground for such a transformation to take place? The following chapter explores the business opportunities and characterizes them. These steps give first insights into the potential of these opportunities. Research question two which builds on these insights (chapter 4) will then show if these opportunities are accompanied by sustainable mental models.

CHAPTER 3: THE INSECT ECONOMY

3.1 INTRODUCTION

This chapter aims to identify, describe and characterize business opportunities around insects as biological resources (research question 1). To do so, 'insects' is set in the context of the Bio-Economy. The Bio-Economy was earlier identified as an economic framework, which is suitable to identify business opportunities related to insects. The sum of business opportunities based on insects will be termed the *Insect Economy*. More precisely, this concept is defined as a subset of innovative and sustainable products, processes, and services resulting from the Bio-Economy, which bases on the use of insects as biological resources (see Figure 14).

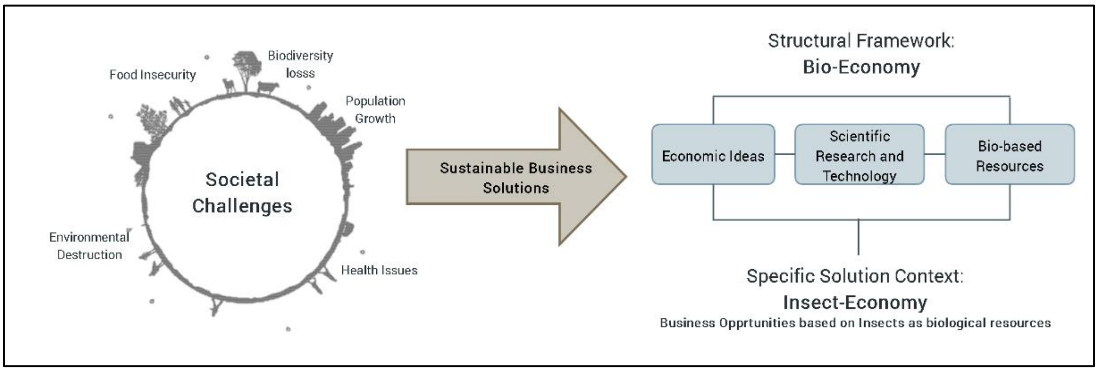

Figure 14: The Insect Economy as part of the Sustainable Bio-Economy

The Bio-Economy consists of three building blocks: (1) economic ideas supported by (2) scientific research in life sciences and (3) enabling technologies related to bio-based resources to create robust business cases. In the first research part of this chapter, insects as biological resources are set in the context of each of these building blocks. Based on these fundaments, emerged business opportunities are identified and described. In the second and final part, the Insect Economy is characterized according to common dimensions and features. For this purpose, morphology is used. Before presenting the research results, however, detailed information on the research data and the research method is provided.

3.2 RESEARCH DATA AND METHOD: MORPHOLOGY

The objective of the morphology is to describe and characterize emergent business opportunities related to insects as biological resources. Morphology was earlier described as a grid that constitutes of verbal, mutually exclusive dimensions and features that comprehensively describe the research subject. The Morphology of the Insect Economy specifically has to constitute of dimensions and features that are related to *insects* and *business*. Moreover, as this research is embedded in the context of *sustainability*, this quality is also part of the morphology[9].

The elaboration of the morphology was no straightforward process. Instead, first information related to insects as biological resources had to be collected, structured and synthesized. While in these processes some dimensions and features of the morphology could already be identified, its elaboration required focused dedication and multiple feedback loops to become a consolidated grid. It is the subject of this section to explain the way the idea of the Insect Economy has been empirically elaborated, the way the morphology was developed and the location of the sources of information.

This narration is written in the first person ('I'). This is a common approach in exploratory research (grounded theory) and recommended by Silvermann (2013) to make the process more illustrative to the reader.

DESCRIBING THE INSECT ECONOMY

To describe the Insect Economy, I structured the information according to the building blocks of the Bio-Economy framework, which consists of economic ideas, scientific research, and bio-based resources. I began (1) by describing the insects from a biological, environmental and human-centered perspective. Then, I related insects to state of the art of scientific research (2). Finally, I explored which past, present and future business opportunities insects as biological resources enable (3). To structure the latter part (3), I adopted the structure of the statistical classification of economic activities in the European Community (NACE).

For the collection of this information and particularly for the exploration of the business opportunities, I drew on data resulting from multiple types of media, including academic sources and secondary literature related to insects as biological resources. The following list provides an overview of the accessed information:

- Academic research stream (e.g., related to (a) Yellow (insect-based) Biotechnology: (Mika et al., 2013, Vilcinskas, 2013b, a), (b) Insects as Minilivestock (Ramos-Elorduy et al., 1997, Paoletti, 2005, Van Huis et al., 2013)).
- Information from company websites whose business model is related to insects (see Appendix 1)

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[9] Whenever is refered to the generic term ‚morphology' it is written in lower cases. When is refered to the Morphology of the Insect Economy, the word ‚Morphology' is written in capital letters.

- Subscription to multiple newsletters, e.g., about animal feed production (e.g., All About Feed), newsletters from start-ups (e.g., AgriProtein), and blogs (e.g., Edible Insects | Entomophagy Daily).
- Conferences (e.g., Insects to Feed the World (2014)/ Wageningen, Insectinov (2014)/ Paris, Bio-Economy Summit (2015)/ Berlin, Symposium "Insekten als Lebens- und Futtermittel - Nahrung der Zukunft?" (2016)/ Berlin, Workshop "Insects as Food and Feed" (2016)/ Wageningen).
- Subscription to google alerts (https://www.google.com/alerts) with the general keyword "insect" in five languages, namely English (insect)[10], German (Insekt), Spanish (insecto), French (insecte) and Portuguese (inseto). The sources of the links provided by the alert are automatic sources of "any region" providing as "many as available." Results are considered relevant if they refer to benefits from insects (e.g., ecosystem services, the discovery of new species, curiosities (e.g., insect hotels, biomimicry) or business-related issues regarding insects as biological resources (e.g., start-ups, business models, latest discoveries in research). Results that I considered mostly irrelevant referred to insects as pests and diseases or information on insects as a nuisance, and pesticides to combat insect pests.

Furthermore, I created a support database in the form of an excel-file (.xlsx) to organize *relevant* information about *business opportunities*. *Relevant* information about business opportunities was considered to be all types of information that are or potentially could result in a business model (e.g., results from applied research). It, however, predominantly contains information about existing companies and in particular start-ups. In total, 75 companies from 22 countries worldwide are listed. This support database was not only helpful to structure the information, but it also helped me analyze it. While the database turned out to be helpful for describing the Insect Economy and for the morphology development, I also used it to select interview partners for the development of the typology. This aspect, however, is subject of the following chapter.

The database constitutes an excel-sheet, and its tabs contained the following structure:

- Information related to the business itself (e.g., company name, geographical origin, industry sector according to NACE, customer segment),
- Information regarding innovation-related characteristics (e.g., business-related types of innovation, dimensions of change, support systems),
- Information regarding sustainability-related characteristics (e.g., Vision and Mission statement of the companies, relation to global challenges, and contribution to the triple bottom line)
- Information regarding insects (e.g., species, cultivation method)

[10] The only differing configuration is the frequency of receiving the alert. Whereby all alerts are automatically sent "at most once a week", the English alerts are automatically sent "at most once a day". I changed the frequency as a result of the trial period between October 2014 and February 2015. During that time the most relevant results appeared from the English alerts.

All in all, this systematic approach – using the Bio-Economy framework and the NACE structure – was useful to filter and synthesize my data. Furthermore, it led to a comprehensive and holistic description of the Insect Economy and served to justify the creation of this concept.

DEVELOPMENT OF THE MORPHOLOGY

The Morphology builds on the theoretic framework of this thesis and an extensive literature research about insects as biological resources. The active process of identifying features and characteristics of the morphology began while describing the Insect Economy. After finishing the descriptive part, I set the focus on the Morphology development itself. In this process, I continued identifying dimensions and features, e.g., by again reviewing the theoretical framework of this thesis. At this stage, the Morphology was a compendium of ideas for possible dimensions and features.

This compendium gained a vital leap in quality while justifying each dimension and its features by formalizing them. During this process, I continued the overall review process and added and deselected elements of the Morphology. This review process by which dimensions were added and deselected followed the logic to characterize the business opportunities of the Insect Economy most plausibly and comprehensively. The result of this process is depicted in Table 7: Morphology of the Insect Economy at the end of this chapter. The morphology was empirically tested during the development of the typology because the fundament is built by the characteristics and dimensions of the morphology. The updated version of the morphology is depicted in section 4.4.

CONCLUSION

In summary, this empirical process passed through multiple iterations and tests. The selected criteria result from logic and follow the principles of comprehensiveness and parsimony. The dimensions and features are the result of an extensive process of data collection and analysis and were developed in an iterative process. This process can be distinguished in two fundamental steps: morphology development based on literature research (chapter 3) and morphology testing based on empirical findings (chapter 4). Despite these iterations, the morphology can be subject to further changes as the Insect Economy develops dynamically.

3.3 THE RELATION OF INSECTS TO NATURE AND CULTURE

This section adopts a natural science perspective and alludes to information on the taxonomy of insects and what distinguishes those species from the other invertebrates. It further explores the discipline of study focusing on insects, namely Entomology and the way sciences evolved around insects. Moreover, the role of insects in relation to humans and the (natural) environment is explored. In fact, while insects are perceived as a nuisance - especially in the western world - they provide fundamental ecosystem services. Those environmental benefits are also in focus.

3.3.1 TAXONOMY OF INSECTS

Insects appeared on Earth over 400 million years ago and can be found in all terrestrial environments (Higgins, 2015). Estimations on the number of insect species available worldwide vary between 10 to 30 million (Paoletti and Dreon, 2005), but only 1.4 million species are described to date (Dirzo et al., 2014). The broad diversity of species makes insects "comprise the most diverse and successful group of multicellular organisms on the planet" (Losey and Vaughan, 2006; p. 311).

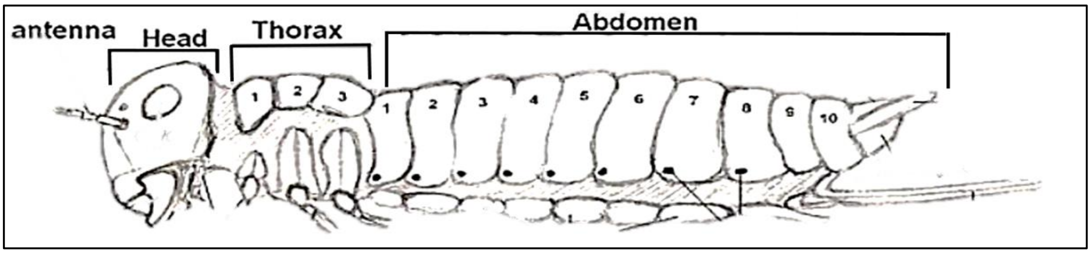

Figure 15: Insect Morphology
Source: (EOL, 2007)

Insects pertain to the taxonomic group of *Insecta* whose morphology is described by a three-part body and a chitinous exoskeleton, which covers the whole body (Johnson and Raven, 2016). The three-part body comprises of a *head*, a *thorax*, and an *abdomen* (see Figure 15). The head consists of sensory organs, such as two antennae and (predominantly compound) eyes, the brain which enables insects to see, hear, smell and taste; and a mouth for food ingestion. As with humans, sensory organs are not only located on the head, but they are distributed across the whole body. However, insects' sensory organs can be very sensitive; e.g., some insects have taste sensors at their feet to taste the substrate of their young. The second body element, the thorax, contains the wings – which most of the insects have and which enable most of them to fly – and it also contains three pairs of jointed legs, which allow them to move on the soil. The third body part, the abdomen, is used for digestion and reproduction. (Berenbaum, 1997)

The exoskeleton – the cuticle - enabled the ancestors 500 million years ago to leave the ocean and to expand in terrestrial areas. It has vital functions, such as protecting insects from water evaporation, from damages, noxious chemicals, and microorganisms, and as a mount for their muscles. It also allows them to camouflage due to the exoskeletons' pigmentation. The cuticle consists of two principal layers: One that makes the insect hydrophobic due to the wax layer (hydrocarbons) and another that makes it resistant and flexible at the same time due to the lightweight combination of the polymer chitin – a long-chained molecule – and proteins. This polymer is becoming increasingly relevant as an industrial material and will be addressed in section 3.5.2.

The chitinous exoskeleton is inelastic and constraints insects from growing. To develop, they have to grow stepwise through molting (*ecdysis*) by which they undergo *Metamorphosis*. The metamorphosis consists of different lifecycle stages, so-called *Instars*, which are characterized by body form, habit, and habitat. There are insects, which undergo a complete metamorphosis from egg or embryo to larva to pupa to adult. Those insects are called *holometabolous insects*. There are also insects which undergo a more gradual process of development, an incomplete metamorphosis, from egg to a series of nymphal stages[11] to adult. Those insects are called *hemimetabolous insects*.

Because insects change their food sources and their habitat during the instars, they avoid competition among each other. Those insects that undergo complete metamorphosis have the greatest habitat mobility, which may explain why almost 90 percent of insect species undergo complete metamorphosis. The habitat mobility can be illustrated on the example of mosquitos. They thrive on bacteria and decomposing plant material in water during their larvae stage while adults feed on blood from invertebrates – such as humans. Hence, when characterizing an insect, it is fundamental to distinguish its instars. (Berenbaum, 1997)

In fact, the number of instars an insect undergoes is highly species-specific. It can also vary depending on the sex, the feed availability and quality, and climate conditions. In fact, with certain species, the sex is determined by the temperature. This peculiarity can, for example, be observed with some mosquitos. When the water temperature is above 28 °C for a constant period of time males cannot thrive anymore so that only females emerge. Anticipating the economic aspects of insects a little, this growth related characteristic of insects is crucial for the selection of an insect species as a bioresource.

Another relevant characteristic is that insects are cold-blooded or *poikilothermic*. This means that the insects' metabolism is not used to maintain their body temperature. To adapt to varying temperature, particularly harsh climates, insects have developed adaptation strategies. A noticeable strategy is entering an inactive phase, named *diapause*. During this physiologic state, their development stagnates, and they live from afore-accumulated fat-reserves.

The diapause becomes of relevance when rearing and "slaughtering" insects. For animal welfare reasons insects can be put into this stage by lowering the room temperature in rearing facilities. It is believed that by doing so, they do not suffer any pain , thereby constituting this practice a humane approach (Halloran et al., 2016).

3.3.2 DISTINCTION OF INSECTS FROM OTHER INVERTEBRATES

The afore-described inelastic chitinous exoskeleton is a body element that insects have in common with other animal species that under folk classification are also considered as insects. However, from a biological perspective, all animal species that have a chitinous exoskeleton are informally denominated as *invertebrates* and pertain

[11] The nymphal stages are growth stages in which the larvae of the insect resembles the adult but certain body elements such as wings or reproductive organs which only develop when adult.

to the superior biological groups of *Arthropods* or *Annelids* (both belong to the taxonomic rank: Phylum[12]).

Annelids, such as earthworms and leeches, are segmented worms that lack other characteristics of Arthropods such as joint appendages[13]. It is believed that *Arthropods* evolved from annelids and developed adaptation strategies to flowering plants. *Arthropods* form the largest Phylum of the animal kingdom with a share of 82 percent (see Figure 16) (Zhang, 2011). They share a set of common traits such as a chitinous exoskeleton, segmented bodies, and jointed appendages. Spiders, mites, ticks, scorpions (Class: Arachnidae), millipedes, centipedes (Classes: Chilopoda and Diplopoda) and crabs, shrimps (Class: Crustacea) and of course insects pertain to this taxonomic group. (Higgins, 2015)

Insects, however, are the most abundant group (approx. two-thirds) of arthropods. It is even the most significant group among the animal kingdom forming 68 percent of it. About 1.07 million insect species are described.

The taxonomic richness of insects is distributed unevenly among the *taxonomic orders*. In total, 39 insect orders have been identified. Five orders, however, stand out for their high species richness: the beetles (*Coleoptera*; ~ 400.000 species); butterflies and moths (*Lepidoptera*; ~ 160.000 species); flies and mosquitos (*Diptera; ~ 160.000 species*) and wasps, ants, and bees (*Hymenoptera*; ~ 120.000 species). The similarities among species of the same order, however, may only be revealed by studying them in close detail (Berenbaum, 1997).

[12] The basic taxonomic hierarchy or classification is generally agreed to consist of Domain, Kingdom (plants or animals), Phylum (e.g. Arthropods or Annelids), Class (e.g. Insecta, Arachnidae, Crustacea), Order (e.g. Orthoptera (Locust), Coleoptera (Beetle)), Family (e.g. Stratiomyidae (family of Hermetia), Genus (e.g. Hermetia), and Species (e.g. Hermetia Illucens (black soldier fly)).
[13] The term originates from the greek word *arthron,* which refers to joint and *pous* to feet. (Berenbaum, 1997, p. 27)

Insects (and other Arthropods) are the least studied animals in the animal kingdom which somehow explains their undistinguished categorization among layman [14] (Johnson and Raven, 2016). Consequently, from a folk perspective, the understanding of what an insect is diverges from the academic definition. Non-specialists tend to classify them according to their size, mobility, and habitat (Yhoung-Aree and Viwat-panich, 2005); and for this reason, in folk classification, insects comprise all Arthropods (e.g., spiders, mites) and Annelids (see Figure 16). However, due to the sheer diversity of the species of the taxonomic group Insecta alone, the focus of this research is restricted to the biological classification.

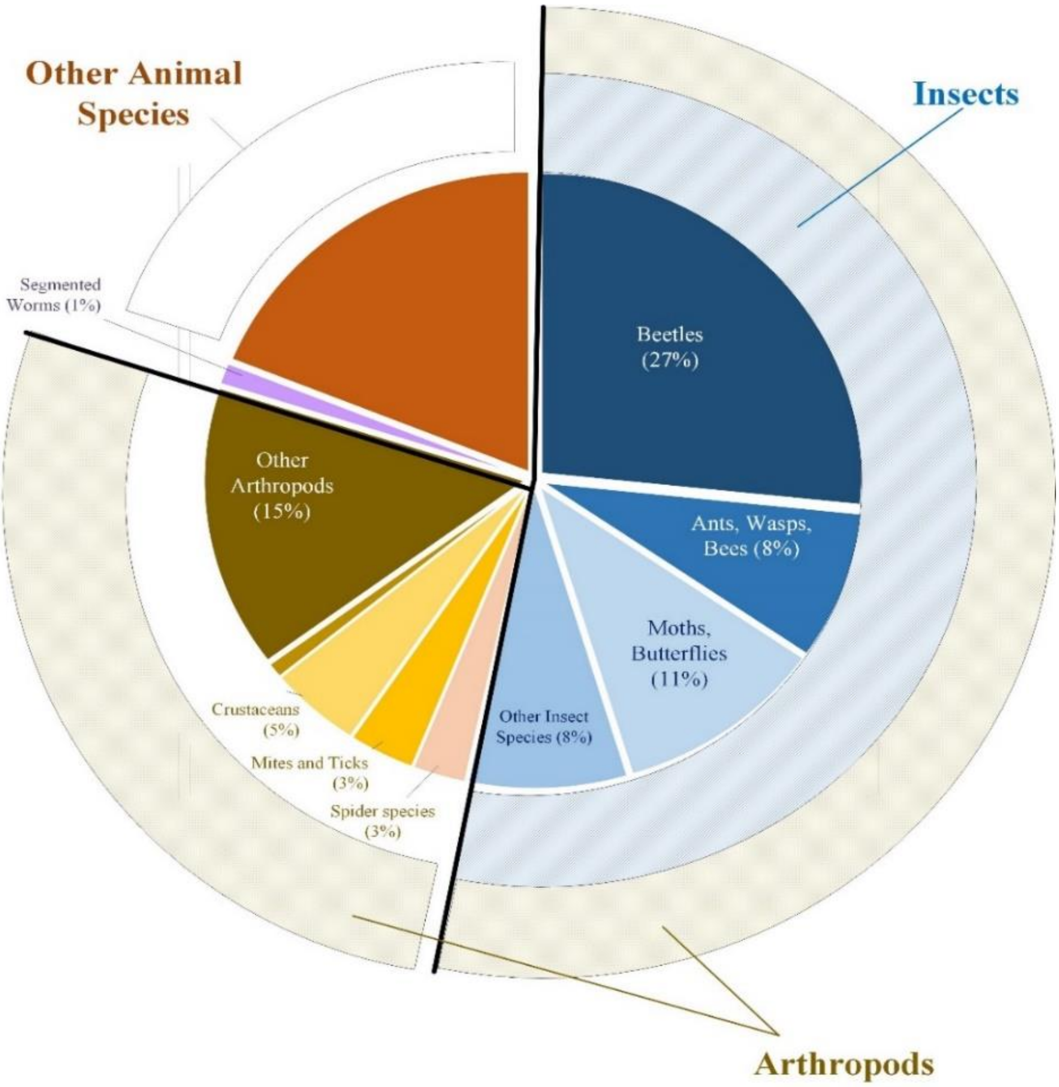

Figure 16: Classification of Insects according to Laymen
Source: Figure based on Zhang (2011)

[14] To increase knowledge on insects, researchers use the virtues of citizen science. Because the diversity of insects is incredibly large, they actively involve interested citizens in research projects, e.g. to explore the diversity of species in a determined area.

3.3.3 INSECTS SHAPING THE ENVIRONMENT - ECOSYSTEM SERVICES PROVIDED BY INSECTS

Insects play a central role in all terrestrial ecosystems. Their extensive array of adaptations, from social behaviors and complex communication to metamorphic cycles and camouflaging mimicry, allows them to persist as one of the most integral aspects of their various habitats. In this section, it will be reviewed in detail to what extent and in which ways insects are beneficial to the environment and for the economy. To do so, the concept of *ecosystem services* is used.

This concept originates from the late 1960s (Millennium Ecosystem Assessment, 2005). During the time that this concept emerged, the natural sciences and economics were widely disconnected from one another. As the economy, however, already produced a significant impact on the environment, it became more and more pressing to adopt an interdisciplinary and holistic view of the problem of studying and managing natural resources. On the one hand, economics had to become more cognizant of ecological impacts and interdependencies, and the study of ecology had to become more sensitive to economic forces, incentives and constraints. (Constanza, 1989)

Thus, the concept of ecosystem services became a tool which enables an interdisciplinary and holistic view on ecosystems and their value for the economy (and society). It does so by assigning an economic value (in monetary terms) to natural systems which influence human welfare. Ecosystem services are “the benefits people obtain from ecosystems” (Millennium Ecosystem Assessment, 2005).

The ecosystems approach[15] plays a central role in Natural Capitalism. Recalling section 2.2.2, principle 3 of Natural Capitalism focuses on investing in Natural Capital, namely biodiversity and ecosystem services, to take away incentives to overuse and degrade it. From a biodiversity perspective, insects form the largest and most diverse group of animals, and as such, they provide invaluable ecosystem services. For example, in healthy soils with a surface of one hectare, an average of 1.3 tons of earthworms and one ton of arthropods can be found together with many other animals, plants, and microorganisms such as bacteria and fungi (Pimentel et al., 1997). Expressed differently, approximately 200,000 arthropods live in one square meter of soil.

In economic terms, Losey and Vaughan (2006) estimate that the annual value of four ecological services, namely dung burial, pollination, pest control of native herbivores and recreation, primarily provided by native insects in the United States, to be more than 52 billion Euros (57 billion US dollars). Reducing the amount of arthropod diversity and biomass - meaning the total mass of living insects in a specific area - leads to reducing and losing ecosystem services they provide. The worldwide recognized entomologist Wilson (1999) estimates that "if [they] all were to disappear, humanity probably could not last more than a few months."

[15] The ecosystems approach often refers to „natural capital“ and „ecosystem goods and services“. For more information see (Robinson et al., 2010).

The reason he adopts such a dramatic position, can be explained through the ecosystem services approach, which the Millennium Ecosystem Assessment (2005) subdivides into four ecosystem services:

- *Supporting Services* which are necessary for the production of all ecosystem services such as nutrient cycling and soil formation;
- *Provisioning services* which englobe products or services that humans rely on;
- *Regulating services* which are vital for the functioning of the ecosystems such as flood control and climate regulations;
- *Cultural Services* which are non-material benefits such as recreational, aesthetic and spiritual;

The ways in which the insects provide ecosystem services are described in more detail in the following sections.

SUPPORTING SERVICES

Supporting services or functions comprise, e.g., nutrient cycling, soil formation, and primary production. They are long-term services and are fundamental for the production of all other ecosystem services, namely provisioning service, regulating service and cultural service (Millennium Ecosystem Assessment, 2005). Especially those insects that are considered *ecosystem engineers* are relevant for generating supporting services. Such species can modify the physical and chemical non-living (abiotic), and biochemical living (biotic) factors of the environment (Wright and Jones, 2006).

An example for modifying the non-living physical factors of the environment is the ability of (earthworms,) termites, and ants to distribute organic material within the soil. They do so by forming channels, creating pores, and building mounds (e.g., termites). In that way, they enhance soil aeration, water infiltration, and retention, which in turn reduces flooding, soil erosion, and runoffs. At the same time, these activities improve the quality and quantity of water (CGRFA, 2009), which also has an impact on plant productivity. (Kremen and Chaplin-Kramer, 2007, Sinha et al., 2008)

An example for modifying the non-living chemical factors is the decomposition of organic matter (chemical factors): dung beetles decompose dung, while flies and carrion beetles feed on dead animals, and termites process large amounts of wood and leaves. By feeding and defecating into the soil, soil-dwelling insects break down complex molecules that plants would otherwise not be able to use (Sinha et al., 2008). They initiate the process of mineralization, e.g., nitrogen fixation - essential for plant growth (Evans et al., 2011). Through this process, forage palatability for livestock is enhanced which is vital in grazing areas (Pimentel et al., 1997).

Moreover, several insect species also “disperse seeds or provide secondary dispersal for seeds, while protecting them from seed predation by burial” (Kremen and Chaplin-Kramer, 2007). Furthermore, the availability of insects promote the diversity of larger animals (biotic factors), such as frogs and insect-feeding mammals and their mounds create habitat for other animals (Evans et al., 2011). Thus, insects can be seen as connector elements forming a crucial link between the living and the non-living environment as well as performing essential functions for an intact running of the ecosystem.

PROVISIONING SERVICES

Provisioning services are primarily understood as the service of providing products that are useful for humans. Such products can take the shape of the physical insects, their byproduct, and biochemical or genetic resources. Honey and silk are well-known byproducts used by human civilization for millennia, and in many world countries, insects are a source of food or feed for livestock (Paoletti, 2005). Because of the nutritional value insects have, the Food and Agricultural Organization (FAO) is promoting insects as a sustainable protein alternative. This aspect is further addressed in section 3.5 about the Bioresources based on Insects.

The insects are also a valuable biological resource from a medicinal point of view. They are used as ingredients in traditional medicine such as in traditional Chinese, Korean and Thai medicine (Pemberton, 2005, Zhi-Yi, 2005, Zimian et al., 2005). One prominent example of the way the insects are used can be shown by weaver ants (e.g., *Oecophylla smaragdina*) and some species of beetles (e.g., *Scarites pyraomon*). Those insects were traditionally used in some world regions such as Algeria, India, and Spain to close open wounds. They possess jaws which are strong enough to clamp skin tissues. In the circumstances such as surgeries, the ants are held close to the body so that they bite the tissue to close it and then their head gets removed from their body. The body fluid that is released by this practice has antiseptic properties and therefore prevents infections. According to Markus (2014), those practices are still kept by indigenous peoples in South and Central America. (Van Huis et al., 2013)

REGULATING SERVICES

Regulating services are vital services for the functioning of ecosystems and comprise services such as disease regulation, pollination, bioremediation and climate regulation. Insects provide all of those services. The following paragraphs will shortly summarize these benefits.

DISEASE REGULATION

Insects are important natural enemies of pest insects and weeds and are therefore also known as ‘biological control agents’ (Kremen and Chaplin-Kramer, 2007). Under natural conditions, almost all pests (99 percent) have between 10 and 15 natural enemies that control pest outbreaks. Among apple orchards, for example, approximately 2000 arthropods reside; about one-quarter of them is considered a pest, one quarter is considered a natural control agent and the other 50 percent is considered to provide overall beneficial services to the surrounding ecosystem (Cross et al., 2015).

The standardization of landscapes through monocultures widely destroyed this natural competition. Only about 4 percent[16] of the originally occurring insects in an ecosystem are estimated to have adapted to the agricultural landscapes, and they are the ones causing 8 to 15 percent of the losses in most major food crops.

It is estimated that without the existence of natural enemies, this value could increase up to 37 percent (Dirzo et al., 2014). Those facts reflect the importance of biological control agents, which are employed in organic agriculture practices (Parisot, 2016). However, conventional agricultural practices destabilize this equilibrium due to monoculture and aggressive mechanical and chemical approaches.

BIOINDICATION AND BIOREMEDIATION

Bioindicators are means to monitor environmental conditions such as water purity or pollution, biodiversity abundance, water and nutrient availability. Insects as bioindicators are under research since the beginning of the 1970s (Van Gestel, 2012), among others, because of their value as a biological resource and their supporting services (McGeoch, 2007, Sinha et al., 2008). Assessing their presence provides information on the health of the ecosystem. However, the amount of available information about the way the species are distributed within a given area is limited and substantial gaps of knowledge remain in virtually all world regions because invertebrate studies lag far behind vertebrate studies. To use this approach with confidence, more (systematic) research is needed.

Remediation activities occur when chemicals are removed from the environment.[17] There exist four general remediation methods, namely biological, physical, chemical and thermal methods. Insects can be used for biological methods to "both decontaminate polluted sites (bioremediation) and purify hazardous wastes in water (biotreatment)" (Pimentel et al., 1997). Some beetles seem to be able to store heavy metals (by using midgut epithelium). When molting a large percentage of these metals get excreted again so that insects avoid getting contaminated (Ewuim, 2013).

INSECTS AS POLLINATORS

For 200 years now, humanity knows that insects are important pollinators (Berenbaum, 1997; p. 134). Bees, moths, flies, wasps, and beetles form the largest group of it. Their service is a fundamental pillar of agricultural productivity and food supply because they stabilize and significantly improve the quality of the yield. 70 percent of

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[16] Almost all insects that feed on plants (90 percent) are *oligophagous* which means that they feed on only three or less plants; so that their physiology is unable to adopt to (all) monoculture plants. A small part of the insect population is even *monophageous* meaning that they feed on only one plant such as the silk moth, *Bombyx mori*. Hence, monoculture landscapes benefit on the on hand those insects which are specialized on this specific plant chosen for agriculture or insects that are *polyphagous* which are those that feed on many plants. (Berenbaum, 1997; p. 153)

[17] Especially the use of earthworms (Annelids), through vermiremediation, can result in cost-effective, low-tech and environmentally sustainable measure to decontaminate soils. Earthworms can be seen as detoxifying agents able to biodegrade or bio-transform several heavy metals, pesticides and organic pollutants in their body. Furthermore, their presence reduces soil salinity and can trans-form non-bioavailable metals for plants into bioavailable ones. For a comprehensive overview on the benefits of earthworms refer to Sinha et al. (2008).

all crop types globally - primarily vitamin-rich crops both fruits and vegetables - depend partially or completely on pollination from insects (Kremen and Chaplin-Kramer, 2007). This service is estimated to be worth 10 percent of the economic value of the world's entire food supply (Dirzo et al., 2014).

Some insects are commercially reared for pollination. The most common example is the European honey bee, *Apis melifera*. However, also the blowfly, *Lucilia caesar*, is commercially reared, principally to pollinate vegetables such as cauliflower, salads, carrots, asparagus, and onions. According to Losey and Vaughan (2006), the economic value of pollination in the United States alone is calculated to be about 300 billion Euros (320 billion US dollars). The economic value of pollination is so important that Pywell et al. (2015) illustrated that converting 3 to 8 percent of arable land to pollinator habitat in the form of wild-life friendly habitats supports greater or equivalent crop yields, even after accounting for the loss of field area.

The service of insect pollination, however, is under threat due to the global phenomenon of pollinator loss. Two aspects related to this problem are addressed in the following paragraphs:

On the one hand, the world experiences the shrinking of biodiversity of pollinizers. Honeybees have become the dominant pollinator providing about 80 percent of all insect pollination for economically relevant plant species (Pimentel et al., 1997). Several monoculture agroecosystems entirely depend on managed honeybees such as almond production in California (Imhoof, 2012). Already in 2004, about one million honeybee colonies were imported to California for pollination (Kremen and Chaplin-Kramer, 2007). This trend threatens resilience for future production (Cross et al., 2015).

On the other hand, scientists and practitioners are studying and acting upon the honey bee collapse or *colony collapse disorder* – a phenomenon that occurs when the majority of worker bees in a colony disappear and leave the queen behind. This phenomenon is linked to a number of causes such as pesticides, drought, habitat destruction, nutrition deficit, air pollution and climate change.

The drop in insect pollinator diversity has multiple effects. For example, Northern Europe experienced substantial declines in relative abundance of plant species reliant on missing pollinators in the past 30 years (Dirzo et al., 2014). The reduction of diversity subsequently causes a shortage of food for other dependent animals on superior trophic levels (e.g., on birds or other insectivores) (Pérez-Méndez et al., 2016).

For humans, the loss of pollinators impacts food quantity and - in an even more significant extend - food diversity, quality (e.g., vitamin, mineral, and sugar content), prices and security. Several trials have been made to pollinate orchards by humans artificially. The results, however, have shown to be poor (Berenbaum, 1997). Due to the fact that there is no substitution for pollination by natural pollinators (yet), their loss is considered as a global threat to civilization.

CULTURAL SERVICES

Apart from the functional value, insects also stimulate fascination due to their intriguing behavior and beautiful appearances in the insect world. The aesthetic value can be experienced through insect observation in the wild or at insect farms (e.g., butterfly farms) but also in insect collections. Furthermore, insects have a recreational value, which can be experienced (directly or indirectly) while hunting and fishing. Altogether, Losey and Vaughan (2006) calculate that the aesthetic and recreational value of insects is worth 45 billion Euros (49 billion US dollars) annually.

Because of their sheer diversity and their ability of adaption, insects are also an object of inspiration for technology development. This approach is known as biomimicry. Mimicry originally studied the insects' ability to camouflage in their environment to misguide their predators (Essig, 1936). Nowadays, biomimicry is described as "a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems" (Benyus, 2002). The open source database of the Biomimicry Institute, AskNature, impressively demonstrates the way innovations inspired by insects promise to promote sustainability.

3.3.4 BIODIVERSITY LOSS AMONG INSECTS

Monoculture is not the only factor that negatively affects the thriving of insects. Additionally, overexploitation of resources, habitat destruction, chemicals, and impacts from invasive species, climate change, and diseases are important drivers. In fact, biodiversity loss of insects is part of a greater phenomenon, which is also determined as *defaunation* being understood as the loss of species and populations of wildlife (Dirzo et al., 2014).

Because research on most insect groups is deficient – especially when it comes to conservation efforts - invertebrate extinctions can easily go unnoticed (Uniyal, 2014). According to Dirzo et al. (2014; p. 401) "Although less than 1 percent of the 1.4 million described invertebrate species have been assessed for threat by the IUCN [acronym for the International Union for Conservation of Nature], of those assessed approximately 40 percent are considered threatened."

Many invertebrate species have not been documented since their original description, and scientists are unaware whether they still exist. In addition, conservation is difficult since many park managers, rangers, and naturalists lack the knowledge and resources to investigate and protect them (Hochkirch, 2016).

The exact impact of insect defaunation is difficult to predict noting the complexity that it entails. However, as insects function as a vital connector element in ecosystems, their decline is likely to produce cascading effects. An example of such a cascading effect (in addition to the loss of pollinators) is the reduction of soil-dwelling insects. Their loss will dramatically impact the decomposition rates and nutrient cycling. Hence, the prediction of Wilson (1999) that "if [insects] all were to disappear, humanity probably could not last more than a few months" contains genuine truth.

The history about the relation of human culture to insects will shed light on the currently disruptive relationship. The following section will, therefore, provide insights into this aspect.

3.3.5 INSECTS AND HUMAN CULTURE

The interest in insects can be traced back to ancient Egypt, where insects were important religious symbols in the ancient culture and mythology. The emblematic insect, the scarab beetle, was believed by Egyptians to ward off evil and protect the owner. This broader role in society is reflected among others in hieroglyphs that figured grasshoppers and artifacts with insect symbols. Furthermore, archeologists could find amulets of grasshoppers, a praying mantis wrapped in mummy linen and mummified and necklaces with symbols showing flies (Walzer, 2015).

Ancient Egypt is not the only ancient society whose culture was connected to the insect world. Japan, ancient Greece, pre-Hispanic peoples in South and Central America, and Australian aborigines were also dedicated to it. In some cultures, this dedication can be explained by the fact that insects were and still are a source of feed, food, and medicine.

In Europe, the medieval teachings on signs interpreted that insects – because of their behavior or physiology or colors - have abilities to cure diseases. For example, because bees possess a hairy body, they could be used by people who suffer from hair loss. The list of possible applications is long, and the most famous one is undoubtedly the Spanish fly, *Lytta vesicatoria*, which is known for its aphrodisiac properties.

In some world regions, such traditional approaches are still practiced such as in Chinese, Korean and Thai medicine. For example, the Institute of Thai Traditional Medicine - which recognizes 42 medicinal insects - states that large red ants as medicine can detoxify the blood, stimulate the pulse and heartbeat, and arrest hemorrhage (Yhoung-Aree and Viwatpanich, 2005; p. 431). Traditional Chinese medicine values insects, their body parts, the products of the insects (eggs, nests, secretions (honey, excreta from silkworms)) or insects in combination with other elements such as bacteria, fungi or parasites. 143 insects are listed in the Handbook of Chinese Medicinal Animal for their medicinal properties.

Furthermore, insects helped crime researchers detect forensic information (Kremen and Chaplin-Kramer, 2007). Forensic entomology studies the feeding behavior of insects on corpses as tools in criminal investigations. They "can be used to estimate the time of death, […] movement of the corpse, manner, and cause of death and association of suspects at the death scene" (Joseph et al., 2011). Using insects for crime detection dates back to the 13th century in China and was first used in a courthouse in the 18th century in France (Joseph et al., 2011).

Insects were also objects of amusement during leisure times. While in Europe, the flea circus was a popular form of amusement, some Asian countries cultivated the tradition of insect duels. The oldest record on this tradition leads back to the 8th Century-China, where male crickets were used. Today, these crickets can cost more than 10.000 Euro which is more than the average monthly wage in China (Berenbaum, 1997; p. 79, MOHRSS China, 2016). In the geographic region, Laos-Thailand-Myanmar, there exists a gambling tradition with rhinoceros beetles (*Xylotrupes gideon*). Depending on the beetle's size and its aggression, its price can vary between a few Euros to 200 Euro (Markus, 2014). This amount is also a considerable amount of money in a country where the average monthly wages are approximately 366 Euro (National Statistical Office of Thailand, 2016).

Figure 17: Illustration of Insects and Plants
Source: (Merian, 1705)

The last relationship between insects and human culture is the long tradition of (hobby) insect collectors who are deeply fascinated by them (see Figure 17)[18]. Their collections, which often focus on a specific insect genus such as butterflies or grasshoppers, are valuable for multiple reasons: They classify insects, safeguard their genetic material, determine the species diversity and protect them.

Despite the many positive relationships that human culture has with insect, the sentiment for insect diverges profoundly according to geographic regions. Predominantly, cultures in developing countries kept their links to the insect world, while others – in

[18] The illustrations from Maria Sibylla Merian stem from her observations from nature and are published in form of books and paintings. Mrs. Merian lived in the 18th century and became famous after her death. Nowadays her books and illustration remain of great value. While some original books are priced at 15.000 Euro (e.g., Erucarum ortus, alimentum et paradoxa metamorphosis), her paintings reside in the hands of renowned art collectors such as the royal collection of England.

particular, westernized societies - developed an aversion to them. Negative experiences with insects are not a new phenomenon, but were already experienced in the cultures above, among others when locust swarms devastated agricultural fields.

However, the widespread negative image of insects in western societies originates from superstitious theories. Those theories spread the belief that insects emerged spontaneously. For example, it was said that they emerge from dust. Essig (1936; p. 88) describes that "Until the dawn following the Dark Ages insect visitations in some places were looked upon as acts of judgment in retribution for sins and were accepted as unimpeachable laws, and were subject to the maledictions of the Church." In fact, the word 'bug' stemmed from those times and referred initially to ghosts and leprechauns (Berenbaum, 1997). Science and technological advances - which are addressed in the following section - began to refute those theories – but not the image.

Further, reasons that contribute to the disgust and negative associations in the collective memory is that insects include many species that are major plant feeders leading to the fact that some insects cause damage on crops feeding on sap, leaves or fruits. Other species feed on blood and thereby cause direct harm to humans, and some are known as vectors for disease transmission, infecting humans, animals or plants. Apart from the fear that emerges due to potential contamination, the awareness about the negative associations is intensified through research findings from medical and economic entomology, which mainly address the economic and social impact caused by the insects.

Despite the ambivalent feelings of people regarding insects, there seems to be a change in perception of the value of insects. People are becoming increasingly aware of the environmental value insects have for the functioning of our ecosystems and build insect hotels to shelter them to survive. This trend can be observed in Europe, where insect hotels are sold in Do-It-Yourself-Stores, but also social projects in schools serve to raise awareness within society about insects. The South Korean capital, Seoul, also plans to build insect hotels with the intention to make the city a greener one and increase the diversity of species in urban parks. The raising consciousness and support of insects to survive is considered vital to preserve pollinators and pest controllers and attract other species such as birds and mammals.

Another case is the one of Insect Respect. Insect Respect is an initiative created by the CEO of the insecticide producer Reckhaus GmbH & Co. KG. The CEO, Dr. Reckhaus aims to make a paradigm shift and create offset areas for the amount of the killed insects by the companies' products. Innovative, for this purpose conceptualized products contain the label 'Insect Respect', where the offset areas are created before the product is sold. Insect Respect products were introduced to mainstream markets in 2017.

3.4 THE SCIENTIFIC KNOWLEDGE ABOUT INSECTS

In this section, the second building block of the Bio-Economy is addressed, namely scientific knowledge. Insects fascinated people since the epochs of Ancient Egypt and Greece. It was, however, during the Roman times when Aristotle (384-322 B.C.) founded the study of insects, namely *entomology*. The term originates from the geek word *entom* which means 'notched' and comes from the physiology of the insects having segmented body parts. The term *insecta* is the Latin translation of it and was first mentioned two millennia later (Berenbaum, 1997).

3.4.1 ENTOMOLOGY AS PART OF ANIMAL SCIENCES

The science of studying insects began with amateur research – primarily based on observation - and formalized into an established field of research at the end of the 19th century.

Until then, entomology could be classified into three branches: systematics, bionomics or ecological entomology, and economics (Essig, 1936). Systematic entomology dedicates to systematically classifying insects into taxonomic groups and describing them according to their physiology. It traces back to the 16th century when Carl Linnaeus established a taxonomic classification (see Figure 18). He introduced the binary system naming each species with the name of the genus (capital letter) and its proper name (small letters). The names always base on Greek or Latin and are written in italics, e.g., *Hermetia illucens*[19]. Systematics is the fundament of entomology because it set the basis for a shared understanding of species, such as the name.

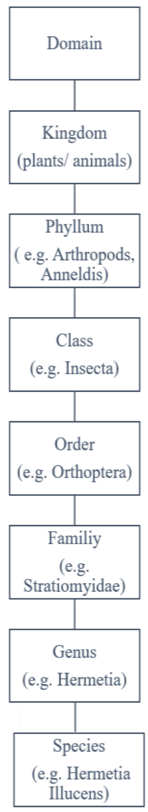

Figure 18: Taxonomic Classification

Ecological Entomology studies biological processes of insects – life cycle, reproduction, habitats and other elements, and positions them into their environmental context. Moreover, economics focuses on the economic significance of insects addressed in more detail in the next section.

Until the end of the 19th century, entomology almost exclusively belonged to the branch of zoology – the study of animals – and thus, to the environmental sciences. At that time, however, environmental scientists mainly focused on large charismatic animals rather than on small and inconspicuous insects.

While especially during the Middle Ages, insects were almost ignored by scientists, the interest increased with the creation of the microscope in the 16th century, the discovery of new continents and expeditions to remote places such as the ones undertaken by Darwin. This evolution led to an upsurge of knowledge of insects and specializations in entomology. Those specializations focus among others on insects in different regions and countries, physiology, insect behavior and specific taxonomies (e.g., myrmecology – the scientific study of ants).

In addition, entomological societies emerged which added much towards the development of the science. There is, for example, the Société Entomologique de France

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[19] The basic taxonomic hierarchy or classification is generally agreed to consist of Domain, Kingdom (plants or animals), Phylum (e.g. Arthropods or Annelids), Class (e.g. Insecta, Arachnidae, Crustacea), Order (e.g. Orthoptera (Locust), Coleoptera (Beetle)), Family (e.g. Stratiomyidae (family of Hermetia), Genus (e.g. Hermetia), and Species (e.g. *Hermetia illucens* (black soldier fly)).

founded in 1882 and the Entomological Society of Philadelphia founded in 1859 and renamed the American Entomological Society in 1861. Besides, Museums contribute to the preservation of knowledge and the study of insects. These times, for example, the Natural Science Museum in Berlin is digitalizing its database of arthropods to close the knowledge gap on insects. The generated knowledge is intended for basic research around insects, for their protection and making informed decisions about insects.

3.4.2 ENTOMOLOGY EVOLVES TOWARDS AN APPLIED SCIENCE

The research focus in entomology took a new path at the end of the 19th century when crop injuries produced by insects became a severe problem. Expanding world trade and increasing specialization in agriculture gave some species a competitive advantage over others. Moreover, the introduction of non-native species (*allochthonous species*), began to become a menace to human systems. *Allochthonous species* possess a competitive advantage compared to native species, if they manage to survive. This can produce high costs, i.e., due to the destruction of electricity lines, crops, and injuries. A prominent example is the Asian giant wasp, *Sphecius speciosus*, and the red imported fire ant, *Solenopsis invicta*.

Indeed, infestations produced by insects were already documented in older civilizations such as Ancient Egypt and were addressed in the Bible, but " little accurate knowledge was developed regarding practical means of their control" (Essig, 1936; p. 110). With the settlement of new continents and the professionalization of the study of insects, awareness has risen, and the specialization of *Economic Entomology* developed. It comprises the study of arthropods related to plant disease, insecticide resistance, and resistance management; biological and microbial control as well as biological pest control (cf. Journal of Economic Entomology). Biological pest control is among the few approaches that investigate the potential benefits of insects in agriculture and becomes increasingly significant due to the modern environmental and health problems caused by chemical pest control (Jehle et al., 2013).

Between the end of the 19th and the early 20th century, medicinal research discovered that insects, particularly mosquitos such as *Aedes aegypti*, were vectors of painful and sometimes deadly diseases such as yellow fever and malaria. In this vein, to combat illnesses caused by insects, the research branch of *Medical Entomology* developed. It focuses on the public health and veterinary significance of insects and other arthropods such as spiders, mites, and ticks (cf. Journal of Medical Entomology). Hence, it is concerned with urban and rural pests as well as the diseases that some insects carry.

Due to the high importance of economic and medicinal entomology to solving practical problems, these fields of research evolved from the zoological branch of entomology and led to the creation of separate fields of research with significant economic and infrastructural equipment. At the same time, it heralds the beginning of entomology as an applied science. Therefore, it created opportunities for the practical use of insects in fields outside the natural sciences and deepened the understanding of the influence of insects on agriculture, livestock, forestry, food systems and human health.

3.4.3 SCIENTIFIC RECOGNITION OF INSECTS INCREASES

The research interest in insects has seen a significant rise. This can be observed when drawing attention to a number of publications in academic journals since the beginning of the 20th century until today. Figure 19[20] illustrates that until the decade of the 1970s only five academic articles were published. From that time on, research attention significantly increased. During the 1990s, publications doubled compared to the previous decade, then (2000-2010) increased by almost tenfold. For the subsequent decade (2011 – 2020) the publications indicate to double again. During the period between 2011 and 2016 (5 years), the number of publications is already higher than during the first decade of the 21st century (2000-2010).

Two observations can be made by analyzing the content of the publications. On the one hand, research subjects are diversifying as new scientific niches. For example, the environmental science branch of entomology sees some "fashion" trends with research foci concentrating on specific species: during the 1960s and 1970s moths, grasshoppers, and houseflies received widespread attention (Chouvenc and Su, 2015). Those insects are known for their impact as pest and disease vector; thus this research focus contributes to negative publicity on insects.

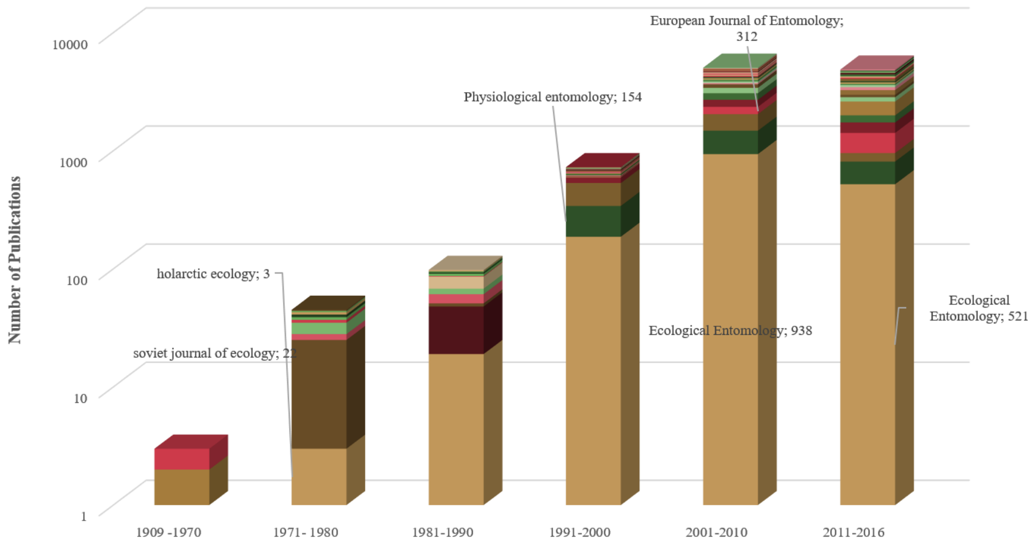

Figure 19: Publications related to Entomology in Academic Journals
Source: Chart based on EbscoHost

On the other hand, the field of entomology is expanding its borders towards the applied sciences. Pioneering technological advances and scientific breakthroughs in other research branches such as in molecular biology broaden the spectrum for research opportunities as well as for practical uses. Thus, entomology has developed

[20] The data base on Ebsco Host – a US-based research databases & discovery service. Here the keyword "entomology" was introduced and the results were discriminated by the selection criteria "academic journals". In total the search engine displayed 24.421 results. Those were split into six periods of time in order to show the evolution of the amount of publications over this period. The data serves as a proxy for the development of the research interest in insects in general.

towards a "large multidisciplinary platform that allows for collaborations from outside insect science (in fields such as genetics, ecology, physiology, microbiology) and non-entomologists" (Chouvenc and Su, 2015; p. 255).

The example of the fruit fly, *Drosophila melanogaster,* is only but one enigmatic illustration of the way the insects contributed to the advances in genetics. The fruit fly has several thousand genes in common with humans and allows for the rapid, cheap and thorough screening of drugs, plant extracts and other compounds in the search for disease treatments. Compared to rats, fruit flies are significantly cheaper, and therefore, the insect can be used particularly in poorer regions. In fact, the organization DrosAfrica makes use of this advantage and aims to do basic research that solves biomedical problems of the Sub-Saharan Africa region by using *Drosophila melanogaster*.

3.4.4 ENTOMOLOGY MERGES WITH BIOTECHNOLOGY

The fruit fly exemplifies an insect that fundamentally contributed to the advances in molecular biology (Berenbaum, 1997); hence to the very origin of biotechnology. This shows that insects were among the first subjects of research in the framework of the Bio-Economy. Recently, insects as bioresources are receiving particular attention in research and for this purpose the research branch *Yellow Biotechnology* was created.

The research on insect biotechnology or Yellow Biotechnology is an emerging field in applied entomology and consolidates entomology with knowledge, methods, and expertise from chemistry, biochemistry, microbiology, molecular biology, chemical engineering and computer science. Thus, Yellow Biotechnology can be understood as the combination of entomology with other natural science fields and technology to insects as a biological resource to manipulate them or their *molecules, cells, organs* or *associated microorganisms*. More specifically, Yellow Biotechnology[21] aims to develop knowledge, products, and services for specific applications in medicine, plant protection or industry. Hence basic research is jointly developed with industrial partners.

Research around yellow biotechnology also draws on inspirations from traditional medicines introduced earlier. Even though according to Western medicine, this form of medicine is considered as pseudo-scientific instead of an exact science, they hold some veracity. For example, earthworms were used since 200 BC in China. Zhenjun and Wenling (2005) list 22 different diseases being able to be cured by using earthworms spanning from the cure of vertigo to epilepsy and cancer. The knowledge about microbiology and biotechnology allows identifying specific active compounds of organisms such as enzymes that are responsible for curing these diseases. Regarding the earthworms, such enzymes were identified, and today the enzyme composition is used in Hong Kong, Japan, Korea, and China to combat cardiovascular diseases. Thus, by combining life sciences and biotechnology with the renewable bioresource 'insect,'

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[21] The color yellow was chosen in order to distinguish insect-related research around biotechnology from other types of research related to it. There also exists "red" biotechnology which relates to the field of medicine, "white" biotechnology which relates to the field of industry and "green" which relates to the field of agriculture.

Yellow Biotechnology contributes to the development of the Bio-Economy and ideally, to solutions to the global challenges. (Vilcinskas, 2013b)

The breaths of the scope of modern applied entomology can also well be illustrated in the example of the International Journal of *Industrial Entomology* (ISSN 1598-3579). It is a peer-reviewed journal that is devoted to the advancement of industrial interest and knowledge concerning sericulture, apiculture, entomopathogenic microorganisms, insect cell culture, insect biotechnology, products derived from insects, insect resources, and related fields.

The greater scope of research also produces a change in the affiliation of entomology to superordinated academic disciplines. Traditionally, entomology is assigned to departments such as animal science (fundamental research) or agriculture departments (applied research). The journal above, for instance, is published by the Korean Society of *Sericultural Sciences* – the science of silk. The interdisciplinary research of the Yellow Biotechnology is, however, more diverse and addresses the fields of medicine, plant protection, and industry. Thus, its dependence expands from the animal sciences (zoology) and agriculture-related research activities towards engineering and other natural sciences.

Scientific and industrial interest in biotechnology and insects is particularly strong in Asian countries (e.g., Korea, China) and Germany. In Germany, it is expected to receive a further boost in the coming years. The national and regional governments invested 30 million Euros in the Justus-Liebig-University (JLU), and specifically the Loewe Center for Insect Biotechnology and Bioresources (ZIB) in 2016.

3.4.5 RESEARCH FOCUS: INSECTS AS FOOD AND FEED

Another research trend can be observed around insects as food and feed. It was already shortly mentioned that insects have traditionally been sources of food and feed in many world countries. This topic, however, regained momentum with the landmark publication of the Food and Agriculture Organization (FAO) “Edible Insects: Future prospects for food and feed security” published by Van Huis et al. (2013). It was published as a response to the increasing threat of food shortages and malnutrition produced by population growth. Insects were thus rediscovered as a potential solution to it.

Since then, research around insects as food and feed is flourishing and receives a substantial lead by the Netherlands and in particular the Wageningen University. Research is also strong in Denmark, where the Nordic Food Lab focuses on the ways of making the food tasty for consumers.

Research findings related to the topic were first bundled in a special issue on “Insects as a Source of Nutrients” published by the open access journal “Animal Frontiers” (Apr. 2015, Vol. 4, No. 1). During the same time, a tailor-made research journal, the “Journal of Insects as Food and Feed” was published for the first time. It covers both, the natural sciences perspective addressing issues such systematics and ecological entomology, and the applied sciences perspective addressing issues such as rearing practices, automation, and technology requirements, but also marketing and other business aspects.

3.4.6 CONCLUSION

In conclusion, the field of entomology has fundamentally changed since its founding times. Moreover, particularly over the last three decades, it has been expanding from a natural science towards an applied – interdisciplinary - science covering a broad spectrum of research branches. Those branches span from food research to more biotech-related fields such as biochemistry and molecular biology.

Ideally, the increased dedication to insects helps tackle real-world societal challenges – this at least is the aspiration of the research of the *Yellow Biotechnology*. While the very commonness of insects may have been responsible for having received little attention during medieval times and reemerged only during the Renaissance; this very commonness may nowadays be seen as an opportunity to natural and applied scientists so that they draw more attention to them.

3.5 BUSINESS OPPORTUNITIES BASED ON INSECTS AS BIOLOGICAL RESOURCES

The information on the ecosystem services provided by insects gave an initial idea about the value that insects as a bioresource have. Also the relevance of insects in science - particularly applied sciences – also provides insights into the potential of using insects in business. The opportunities that insects as bioresources enable are the focus of this section.

The results of the exploration of business opportunities are structured according to the statistical classification of products by activity in the European Economic Community (acronym CPA) (Council Regulation (EEC) No 3696/93). The CPA is part of an integrated system of statistical classifications such as the statistical classification of economic activities in the European Community (NACE)[22] and was developed mainly under the auspices of the United Nations Statistical Division. This system makes it possible to compare statistics across countries and in different statistical domains.

The classification structure begins with the section and subsequently narrows down to divisions, groups, classes, categories, and subclasses of the products of activity. This structure is adopted, and insect-related products by activity are allocated to the lowest hierarchical level possible. For the allocation, the nomenclatures database RAMON was used.

Some products of activity are currently widely used, others are dynamically developing, and more are expected to become increasingly prominent in the future. Therefore, the information will comprise of historical, present, and potential future uses. Instead

[22] CPA product categories are related to activities as defined by NACE and the CPA is a structure parallel to that of NACE at all levels.

of merely mentioning the products and services, comprehensive explanations are provided. In the end, an overview gives the summary of the products and services obtained by using insects.

In some cases, one company covers a whole range of sub-processes. The classification procedure of the CPA would consider such an integrated series of activities as one activity within the same statistical unit. This approach, however, would not allow exploring the full breadth and scope of activities taken out in the Insect Economy. Therefore, it is more suitable to break them down into different categories of the classification, which is the way I pursued in this section (Eurostat, 2008).

3.5.1 PRODUCTS OF AGRICULTURE, HUNTING, AND RELATED SERVICES

This division includes activities related to agriculture and the production of animal products. Activities that require any subsequent processing of the agricultural products are classified under the division of Manufactured Products (Eurostat, 2008).

01.49.19 _OTHER FARMED ANIMALS, LIVE

In recent years – in particular since 2013, when the report on Edible Insects was published – an increasing number of mass rearing facilities for insect farming has built up. Their purpose usually is to rear insects as:

- Feed for chicken, pigs, and fish which can be fed with live insects
- Ingredients for food production or (compound) feed production for farm animals or aquaculture
- Raw materials for other industrial purposes.

In some developing countries, insect farming is a tradition. In Thailand and India for instance, insects are reared and processed at household level or at small-scale for self-sufficiency or sale on local markets (Van Huis et al., 2013). In some rural areas in Thailand for example, the income from ants accounts for almost 30 percent of the total household income for ant collectors, besides providing their families with an animal food source (Siriamornpun and Thammapat, 2008). This activity is also a good opportunity for women and children to guarantee their substance as they tend to suffer more from inequalities in poor regions.

01.49.21 _NATURAL HONEY

Beekeeping – *Apiculture* - was already practiced in Egypt and Mesopotamia. Since these times, bees were studied for their social structure and of course the products - in particular, honey - they produce. Honey is probably the oldest sweetener of the human civilization. During the Middle Ages, it became largely substituted with sugar from sugar canes, which were introduced from the newly discovered continent (Essig, 1936; p. 85). Still, it remained important enough that at the times of colonialization of North America, settlers introduced honeybees to their new homeland. Before that, no honeybee species inhabited the American content. (Berenbaum, 1997)

Modern beekeeping primarily relies on the honeybee, *Apis mellifera*. This species originally stems from Europe, West Asia, and Africa and has developed special traits to adapt to the conditions of the region. For some time now, however, *Apis mellifera* suffers from a parasite, the mite *Varroa destructor*. Other environmental conditions also complicate the bees' survival. Therefore, it can be expected that the African honey bee, *Apis mellifera scutellata* displaces the common honeybee as it is more resistant to these factors.

01.49.24 _EDIBLE PRODUCTS OF FARM ANIMAL ORIGIN

To apply this category to insects, the concept of "farm animals" needs to be extended. Edible products of farm animal originate in a broader sense are products obtained from lac insects and the honey bees. Insects are usually "farmed" through semi-cultivation. Semi-cultivation involves manipulating an insects' habitat, to improve the insects' availability, predictability, and/or productivity. Thus the insect is not reared in a closed environment but remains in its natural environment. The honey bee and the lac insects are two insects managed in this manner.

Royal jelly, *pollen,* and *propolis* are other by-products obtained from Apiculture. Royal jelly is the feed that working bees feed to the larvae of the future beehive queen. From a nutritional perspective, it contains a variety of nutrients including minerals such as calcium, copper, iron, phosphorous, silicon, sulfur, and potassium, as well as the wealth of vitamin B and 17 different amino acids (Organic Facts, 2016). This royal feed is associated with innumerable health benefits such as lower blood pressure, ability to prevent cancer, inhibiting inflammation and antibiotic properties along with the ability to regulate the immune system. It also seems to have effects on the levels of cholesterol and the nervous system with insulin-like properties (Wolters Kluwer Health, 2010c).

Pollen is obtained from pollination by worker bees. The bees pack them into small dust pellets and combine the pollen with plant nectar and bee saliva. It is then used as a food source for the male drones. Bee pollen is considered a 'superfood' because of its nutritional properties. It is rich in protein, vitamins, minerals, trace elements, enzymes, amino acids and other compounds. The properties vary depending on the geographic area and the plants that the bees feed on. Usually, the pollen preparations contain mixtures of pollens from diverse types of plants. Bee pollen is traditionally used for a variety of purposes, including relief of constipation, prostate cancer, wound healing, and antioxidant action. It may also relieve premenstrual syndrome and climacteric symptoms associated with menopause (Wolters Kluwer Health, 2010a).

Propolis is another by-product obtained from bees. Bees obtain it from tree bark resin and mix it with some honey. They use it as an antiseptic adherent to close their bee hives or to embalm dead intruders of the hive such as mouse carcasses. In that way, they avoid getting infected with dangerous microbes, bacteria, viruses, and fungi. The compound is a sticky, greenish-brown mass with a slight aromatic odor also known as propolis balsam, propolis resin, propolis wax, or bee glue. The list of health benefits seems infinite and includes the ability to discourage infections, serve as a natural antibiotic, a supporter of the immune system and dental care. While royal jelly and bee pollen lack sound clinical studies that confirm the health benefits, propolis is widely researched in particular for its benefits for dental health (Wolters Kluwer Health, 2010b).

In the future, new edible products of farm insects might be introduced, such as cockroach milk. Indeed, there is one cockroach beetle that gives birth to live offspring (this means that it is *viviparous*).It has developed the sense of motherly care. This species is the Pacific beetle cockroach, *Diploptera punctate*, which feeds its young through fleshy organs called brood sacs with a liquid substance packed with fats, sugars, and protein. This liquid is also drinkable by humans. “Experiments conducted [by the biochemist Subramanian Ramaswamy] suggest that cockroach milk is among the most nutritious and highly caloric substances on the planet, according to research published recently in the journal for the International Union of Crystallography” (Sachan, 2016). Therefore, it is considered a potential superfood. Of course, cockroaches cannot be milked as cows can. Therefore, probably the milk extraction will take place through bioengineered yeast that is already used in the food industry (Guarino, 2016). However, the feasibility of this solution needs to be further evaluated.

01.49.25 _SILK-WORM COCOONS SUITABLE FOR REELING

Silkworm production – *Sericulture* – is one of the oldest industries in the world, which existed since 3000 B.C. Chinese emperors, who first excelled in this industry jealously fought over the secret of silkworm rearing. The rearing process comprises the cultivation of the mulberry tree – the only feed source of the silkworm (which means that they are *monophagous*) - the rearing of silkworms, the reeling, and weaving of silk. Treachery of this well-hidden secret was under penalty of death.

Still, also Europe and the United States possessed a powerful silk industry, however, sericulture is very labor intensive, and the high requirements for the production incentivized the growing introduction of synthetic fibers. Sericulture is still a high-value activity in some countries. In particular, it is the primary source of income to many poor and landless farmers, and to women. The world’s largest producers are in Asia, specifically China, Japan, and India. (Berenbaum, 1997)

The production of silk receives a stand-alone category in CPA under the principal category ‘Manufacturing,’ namely 13.10.4 _Silk yarn and yarn spun from silk waste. Hence, silk and its benefits are addressed under this category.

01.49.26 _INSECT WAXES AND SPERMACETI

A commonly used wax is the honeybee wax. It is the result of an innumerable digestion of flower nectar by honey bees. Beeswax is used for centuries as candles, as dent imprint in dental medicine, adhesive, and shoe and furniture polisher, as an ointment and, suppository. The list of uses can be infinitely extended. Artists such as Madame Tussaud used it for their sculptures, which are still exhibited at the famous waxworks cabinet (Berenbaum, 1997). The applications from the past went only partially obsolete. Its use as cosmetics, sweet and industrial lubricant is still prevalent.

01.61.10 _SUPPORT SERVICES TO CROP PRODUCTION (E.G., PEST CONTROL FOR AGRICULTURE)

The most important support services used in agriculture today are integrated pest control and pollination. Those benefits were already illustrated in section 3.3.3 about ecosystem services provided by the insects.

BIOCONTROL

First records for biocontrol were found in the 13th century China, where farmers used the weaver ant, *Oecophylla smaradina*, to protect citruses and lychee trees from pests. The concept of biological control, however, was first introduced in 1919 by H.S. Smith (Berenbaum, 1997; p. 230-232). Biocontrol uses biological agents such as insects as natural enemies against pest insects. Therefore, a wide array of insect species is commercially reared and used on agricultural fields.

Despite its potential, biocontrol is far from being fully exploited to date because only a fraction of insects as biocontrol agents are known. This lack of knowledge can partially be explained by the fact that biocontrol is complex. Effective biocontrol requires profound knowledge of ecosystems and their interconnected relationships. Furthermore, the natural enemies used for biocontrol often stem from other regions (they are *allochthonous*). Hence their adaptation strategies and wider effect on the ecosystem needs to be researched before introducing them into their new habitat – an activity that is very time intensive.

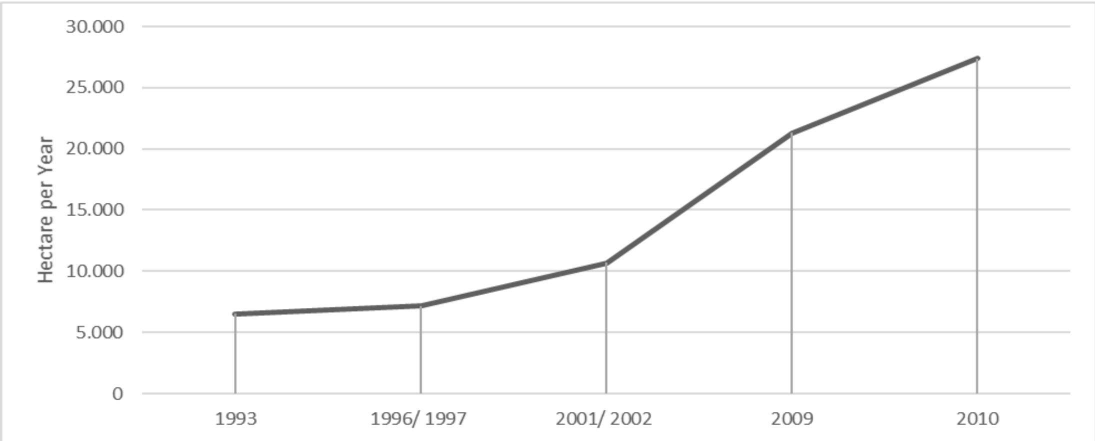

Figure 20: Use of Insects for Biological Control between 1993 and 2010
Source: (Jehle et al., 2013; p. 81)

Despite these requirements, the Commission on Genetic Resources for Food and Agriculture (2009) estimates that biocontrol is – in comparison to conventional pest control methods - highly competitive in a growing number of situations. The status report of the Federal Research Institute for Cultivated Plants in Germany (Jehle et al., 2013) registered an increase in the use of insects for pest control as shown in Figure 20. The increasing consumer distrust against traditional agricultural practices and policies that promote the shift towards organic produce make biocontrol an indispensable alternative. Furthermore, biocontrol can become increasingly competitive with synthetic methods.

An example of agricultural region where farmers are forced to change their practices is Almeria (Spain). It consists of approximately 280 square kilometers of agricultural land where produce is the main source of income for the residents. However, rising prices, competitiveness, consumer awareness about the adverse environmental impacts of agricultural practices and diseases are forcing those practices to change. Since 2007, progressive farmers have been applying biocontrol and pollination (Urban, 2014).

Apart from being used for pest control, insects can also be used for weed control because the largest part of insects is *oligophagous*, meaning that they feed on less than three plants, and some are even *monophagous*, feeding on only one plant. Hence, specific species can be used to feed on the most common weeds instead of using fungicides or herbicides.

STERILE INSECT TECHNIQUE

The Sterile Insect Technique (acronym SIT) is a method of biological insect control, whereby overwhelming numbers of sterile (male) insects are released into the wild. The sterile males compete with wild males to mate with the females. When females mate with sterile males, they produce no offspring, and in consequence, the population of the next generation reduces. Furthermore, sterile insects cannot self-replicate and, therefore, cannot become established in the environment. The release of sterile males is usually repeated multiple times until the pest populations are reduced to the desired number.

The sterile insect technique (SIT) varies according to the insect species and is commonly applied to control pests (pest control) that attack crops and pests that spread diseases (vector control). The fruit fly is the world's most damaging fruit and vegetable insect pest, most notably the Mediterranean fruit fly, and the Mexican fruit fly, *Anastrepha luden*. Moreover, the most dominant disease vectors are the tsetse fly, which transmits the sleeping sickness and the mosquitos *Aedes aegypti* and *Aedes albopictus*, which transmit malaria, dengue, yellow fever and the Zika virus.

SIT is used since the mid-20th century. It works by exposing reared insects to irradiation on their reproductive cells, which produces sterilization. An alternative to SIT is the application of modern biotechnology to pest insects called *self-limiting approach*. It consists of genetically modifying the target insect. In the case of *Aedes aegypti* for instance, the mosquito is engineered to contain a self-limiting gene that causes their offspring to die before reaching adulthood. As with SIT, the genetically modified insects get repeatedly released in sufficient numbers until a point when the level of wild population is below the level of possible disease transmission.

POLLINATION

As described earlier, pollination by insects is indispensable for plant growth and the development of many fruits and vegetables. Primarily organic farmers are using this function and buy or rent most commonly honeybees, bumblebees or wasps for their services across agricultural production systems stretching from peri-urban horticultural systems to large-scale fields. The honeybee, *Apis mellifera* – the same species which provides humans with honey - is utilized for at least 90 percent of managed pollination services. For instance, the production of sunflower seed is indispensably linked to the pollination by the common honey bee.

Recalling that until about 200 years ago scientists were unaware of the services of pollination provided by insects, knowledge gaps remain. The FAO states that "production increases in a number of crops which were until recently thought not to need pollination." For instance, the preservation of forest patches near coffee plantations in Indonesia and Costa Rica have shown to increase populations of pollinators and led to increased productivity of the crops (CGRFA, 2009; p. 3).

OTHER SERVICES: SOIL QUALITY ENHANCER

In the section about the ecosystem services provided by insects (3.1.3), the benefits of insects to improve soil quality were addressed. Well-known ecosystem service providers or ecosystem engineers are termites and ants. However, their services are still widely neglected from an economic perspective.

A study from Evans et al. (2011) establishes a link between the environmental and economic benefits of using ecosystem engineers. In their field experiment in Australia, they show "that ants and termites increase wheat yield by 36 percent from increased soil water infiltration due to their tunnels and improved soil nitrogen" (2011; p.1). From these results, they concluded that these *ecosystem engineers* are ideal for the sustainable management of production landscapes.

As the world experiences decreasing soil quality and topsoil loss, among others due to aggressive agricultural practices, this predominately overlooked opportunity might become increasingly profitable and therefore, more and more exploited. Indeed, the use of insects will only be one part of the soil management technique knowing that more organisms inhabit the soil such as mycorrhiza, bacteria, and other arthropods such as millipedes, centipedes, slugs, and snails. Each organism has a specific ecosystem function and contributes to soil health.

3.5.2 MANUFACTURED PRODUCTS

Manufactured products are the result of the physical or chemical transformation of materials, substances, or components into new products. The materials, substances, or components transformed are raw materials that are products of the primary sectors such as agriculture and fishing as well as products of other manufacturing activities. Substantial alteration, renovation or reconstruction of goods is considered to be manufacturing. The output of a manufacturing process may be finished in the sense that it is ready for utilization or consumption, or it may be semi-finished because it will become an input for further manufacturing. (Eurostat, 2008)

10.41.19_OTHER ANIMAL FATS AND OILS AND THEIR FRACTIONS

Oil is a chemical substance which – depending on its properties – can be used in versatile ways, namely as an ingredient for food and feed, but also as an industrial product. The most dominant use of insect oil is currently assigned to animal feed where it becomes part of the compound feed – feedstuff that is blended with various raw materials and additives.

In Europe, insect oil as part of compound feed was first introduced in 2016 in the Netherlands (Koeleman, 2016b). There, the Poultry Research Centre showed that chickens benefit from insect oil when it comes to growth and feeds conversion as compared to soybean oil. Additionally, it is easy to digest and contains health-promoting properties. Both chicken and pigs store the oil in the meat, which is why consumers benefit from the insect feed. This benefit is a good quality argument for using insects as feed supplements.

Companies such as HiProMine (Poland), Bioflytech (Spain) and Protix (Netherlands) and Entologics Nutrients Sustentáveis (Brazil) focus on the feed market, targeting specifically the fish and the poultry feed market. The pioneer AgriProtein (South Africa) promotes insect oil for the pet food market as well as for industrial swine production due to its high unsaturated fatty acids, Omega 6 and its high palatability.

Insect oil can also be used for human nutrition because the fatty acids in insects are similar to those in poultry and fish. Some insects even contain more essential fatty acids, such as linoleic and/or linoleic acids than meat. Because of their beneficial health properties, the oil from mealworms, beetle larvae, crickets, cockroaches, and grasshoppers has been tested as cooking oil by Wageningen University, e.g., for salad dressings (Wimhurst, 2016). Furthermore, the start-up Biteback from Indonesia sees great potential in promoting insect oil as a substitute for palm oil.

Insect oil is also considered a potential biofuel. Some insects, such as watermelon bugs (*Aspongopus viduatus*), sorghum bugs (*Agonoscelis pubescens*), black soldier fly larvae (*Hermetia illucens*), oriental latrine fly larvae (*Chrysomya megacephala*) and darkling beetle larvae (*Zophobas morio*) have been reported as an alternative feedstock due to their moderate growth rate and high lipid content. To date, the technology to produce biofuel from insects is not mature enough to be cost-effective. Moreover, the environmental benefits require further research. Still, Sawangkeaw and Ngamprasertsith (2013) conclude that insect oil is a potentially viable source of energy. Notably, the derived oil from the Black soldier fly prepupae shows promising potential for producing “high-quality biodiesel” (Surendra et al., 2016; p. 199) as it contains crucial biofuel properties, namely density, viscosity, flash point, and Cetane index. HiProMine (Poland) is exploring this potential as well as the use of insect oil for the pharma and beauty industry.

Indeed, the use of oils is widely applied in industry for various purposes for example as industrial lubricant or paint. The lipid properties vary depending on the species (Sawangkeaw and Ngamprasertsith, 2013). However, the press release of a Market Study on edible Insects states that the use of insect oil for industrial purposes is currently explored for cockroach oil[23] (Hall, 2016). Furthermore, the company Danico, which produces bio-based oils, sees potential in using it as machine lubricant; however, tests remain to be undertaken (personal communication).

In conclusion, the application for insect oil is still in its infancy. Industry pioneers aim to establish it as an ingredient for compound feed. However, industrial uses also show

[23] The report published by Persistence Market Research in 2016 costs US 4.900 Dollar and could therefore not be fully accessed.

potential such applications in the pharmaceutical and the beauty industry, insects as biofuels and other uses.

10.89.19_MISCELLANEOUS FOOD PRODUCTS

Nowadays, two billion people regularly practice *entomophagy*, which means that they use insects as part of their diet (Van Huis et al., 2013). Precisely 2037 species are declared as edible insects (Jongema, 2015). The most preferred insects belong to the order of beetles (Order: Coleoptera), followed by caterpillars (Order: Lepidoptera), ants, wasps and bees (Order: Hymenoptera), and grasshoppers and locusts (Order: Orthoptera) (see Figure 21).

The most diverse number of insect species (679 out of 1,745) is consumed in America, followed by Africa (with 572 different species) and Asia (349 species). Only 41 edible insect species are registered in Europe according to Ramos-Elorduy (2005). Here, as well as in other western countries, consumers are reluctant to consume them. Of course, there are some exceptions such as when it comes to the production of cheese. The French cheese ‘mimolette’ generates its grey crust from mites and the Sardinian cheese ‘casu mazu’ matures with the help of the fly *Piophila casei L.* and is eaten together with the larvae.

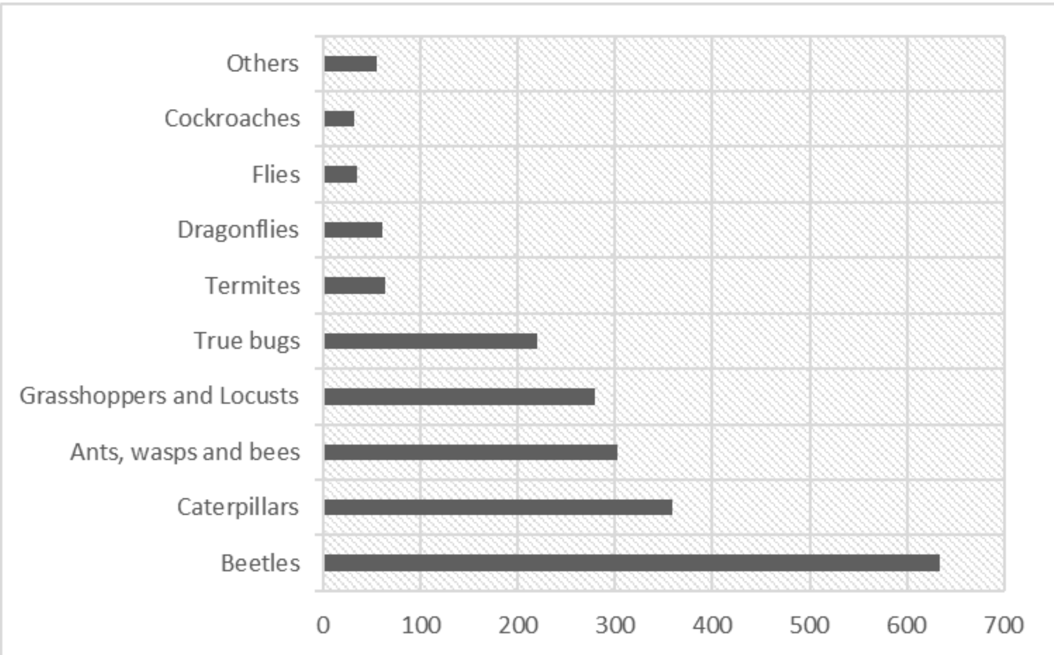

Figure 21: Number of Edible Insect Species clustered in Insect Orders
Source: (Jongema, 2015, AgriProtein, 2017)

As already explained, in developing countries, insects are used for subsistence and as a source of income. Because of the ease of insect rearing, it is also considered a valuable emergency food particularly in times of nutritional insecurity for the soldiers on military missions (Van Huis et al., 2013).

NUTRITIONAL VALUES

There exists a broad spectrum of insects that has been identified to have a high nutritional quality which is the reason for their promotion as a source of food and feed. The Nutritional value is determined by the amount of protein and the quality of protein, which in turn is determined by the amino acid composition and the digestibility of the protein. (Siriamornpun and Thammapat, 2008)

According to Ramos-Elorduy (2005), the protein content of insects vary from 30 to 81 percent and ranges from 40 to 75 g per 100 g dry weight, which is comparable to the protein content of meat. Furthermore, the protein shows a high protein digestibility (70 to 98 percent) and concentration of essential amino acids[24] (46 to 96 percent of the nutritional profile) for the analyzed species[25]. The analysis shows that insects can cover between 46 to 96 percent of the preschooler and adult requirements indicated by the Food and Agriculture Organization and the World Health Organization.[26]

Apart from proteins (and lipids explained in section 10.4), insects also offer a broad spectrum of micronutrients. Those include copper, iron, magnesium, manganese, phosphorous, selenium, and zinc. These micronutrients are in several cases superior to conventional foodstuff including milk, eggs, pork, chicken or ham (Ramos-Elorduy, 2005; p. 277, Yhoung-Aree and Viwatpanich, 2005; p. 432 - 433, Zhenjun and Wenling, 2005).

A comparison between the nutrient content of insects and conventional livestock is provided in Table 1.[27] For example, the energy content of 100 gram of insect and 100 gram of fresh meat is similar – except for pork due to its extremely high-fat content. However, the insects are better protein sources by weight in comparison to beef, and pork. For an overview Sun-Waterhouse et al. (2016), Payne et al. (2016), Nowak et al. (2016) and Rumpold and Schlüter (2013) provide comprehensive datasets.

Table 1: Comparison of nutrient content of conventional food to insects

[24] Amino acids are organic compounds that combine to polypeptides which then form proteins. For that reason amino acids are considered the building blocks of life. They are necessary to break down food, for growth, tissue reparation, and to perform body functions, such as giving cells their structure and removing of all kinds of waste produced in connection with the metabolism. The 21 existing amino acids can be classified into three groups, namely essential amino acids (9), nonessential amino acids (8) and conditional amino acids (4). The essential amino acids, namely histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine, cannot be produced by the human body and must therefore be obtained from food. The nonessential amino acids are produced by our body and conditional amino acids are required in times of illness and stress. (Wax, 2015)

[25] Ramos-Elorduy et al., 1997 studied 78 species which are commonly consumed in the Mexican State Oaxaca.

[26] Two essential amino acids, namely Tryptophan and Lysine, are deficient in the profiles and need to be obtained from other food sources. To overcome this bottleneck Verkerk et al. (2007) proposes to engineer the nutritional value of the insects by altering the insect cells, infecting them with a virus, specifically with the recombinant baculovirus. This approach, which uses modern biotechnology, would be a solution to enrich insect cells with missing essential amino acids such as lysine and tryptophan.

[27] In addition to the quoted references, comprehensive overviews can also be found in Ramos-Elorduy (2005) and Rumpold and Schlüter, 2013.

Food	Energy in Kcal/g	Protein (g)	Fat (g)	Riboflavin (mg)	Phosphorus (mg)
Milk, sterilized	61,0	3,3	3,4	0,2	82,0
Eggs, fresh	155,0	12,8	10,8	0,6	230,0
Pork, minced	229,0	18,2	17,0	0,1	170,0
Chicken	193,0	28,6	8,7	0,2	171,0
Beef	183,0	26,3	8,0	0,2	210,0
Ground Cricket (*Acheta confirmata*)	188,0	17,5	12,2	0,8	143,0
Bombay locust (*Patanga succincta*)	169,0	20,6	6,1	1,9	238,0
Silkworm pupae (*Bambyx mori*)	127,0	12,2	7,0	1,1	167,0
House fly pupae (*Musca domestica*)	91,8	19,7	19,0	0,8	372,0
Black soldier fly larvae (*Hermetia illucens*)	199,4	175,0	140,0	0,2	356,0

Source: Yhoung-Aree and Viwatpanich (2005; p. 432-3), (AgriProtein, 2017), Van Huis and Dunkel (2017) and Finke (2013) for the examples: housefly and black soldier fly.

It is important to notice that the nutrients of insects seem to be readily absorbable by the human digestive system (bioavailability). An experiment with grasshoppers, crickets, mealworms and buffalo worms could show that insects have more bioavailable iron, calcium, copper, magnesium, manganese, and zinc than a beef steak.

INSECT SPECIES

Notwithstanding the diversity of existing edible insects, in Europe and the United States, there is a tendency to prioritize on the insects depicted in Table 2:

Table 2: Insect Species as Food for Industrial Production in EU

Latin Name	Common Name
Acheta domesticus	House **cricket**
Achroia grisella	Lesser wax **moth**
laevigatua	Lesser mealworm **beetle**
Bambyx mori	Silk **moth**
Galleria mellonella	Greater wax **moth**
Gryllodes sigillatus	Banded **cricket**
Gryllus assimilis	Field **cricket**
Locusta migratoria	Migratory **locust**
Schistocera americana	American desert **locust**
Tenebrio molitor	Mealworm **beetle**
Zohobas atrastus morio	Giant mealworm/ Superworm **beetle**

Source: (Scientific Committee of the Federal Agency for the Safety of the Food Chain (Belgium), 2014)

The reasons for this prioritization are first of all that these species (Table 2) show promising characteristics for being cultivated in controlled and automated environments separate from ecosystems (Van Huis et al., 2013). The second reason leads back to compliance with legal requirements as well as the process requirements for large-scale production. As with the selection of farm animals, a similar selection process is applied to insect species for food (and feed) production.

DEVELOPMENT OF INSECTS AS FOOD

According to a market study conducted by Global Market Insights (2016)[28], the global edible insects market is segmented into Asia Pacific, North America, Middle East and Africa, Latin America and Europe. The Asia Pacific industry is dominated by Thailand and China, and in 2015 it was the most important region for edible insects with more than 10.1 million US dollar revenue generation. Indeed, in 18 out of 44 Asian countries people consume insects as food. For this reason, several Asian countries have developed strategies to foster a national Insect Economy. Thailand, Vietnam, Laos, and Myanmar, for instance, maintain cross-border trade with insects as food (Yhoung-Aree and Viwatpanich, 2005). Additionally, South Korea, whose edible insect sector accounted for 4.8 million Euros (6 billion won) in 2012, is planning to expand it to 49 million Euros by 2020 (61 billion won) (Jeong, 2014, Chung, 2016).

There are different ways in how insects can be consumed. They can be eaten whole (cooked or occasionally raw, including those added in alcoholic beverages such as Mezcal), or as processed products in ground and paste forms. Moreover, they can be processed into less recognizable forms, e.g., into extracts of protein, fat or chitin to use them in snacks, crackers, pasta, bread, sausages or meat loaves as well as unique dishes in restaurants.

Insects as food and food supplements can be sold as products with low up to high value added. While in countries such as Thailand, Laos, Vietnam and Mexico, edible insects are considered staple food and therefore, generally economical. In other countries and regions (e.g., western countries but also developing countries such as Uganda), the consumption of insects is a delicacy and therefore, high priced. Examples of such delicacies are palm grubs, termites, caterpillars, crickets, and grasshoppers. In the Democratic Republic of Congo for example, "a kilogram of crickets costs about 45 Euros (50 US dollars) in 2015, more than twice the price of beef" (Ross, 2015). Moreover, in Uganda, a kilogram of grasshoppers can cost 7.3 Euros (8 US dollars) per kilogram — double the price of minced meat—during grasshopper season. Off-season the price might even rise to 45 Euros (50 US dollars). It is estimated that grasshopper-traders produce 45 million Euro (50 million US dollar) annual turnover in Uganda (Wasswa and Palitza, 2014).

The value-added can also vary depending on the way the insects are marketed. Insects in their original shape (sold whole) usually have a lower value-added – unless they are sold as exotic snacks – than ground or paste forms. The more the product is transformed into, e.g., protein bars or insect burgers, the more value-added is created.

Furthermore, their nutritional quality opens market opportunities in the wellness food, therapeutic food or superfood segment in which products can be sold at higher prices. The categorization of insect-based food as superfood stems from the high-quality protein and the bioavailability of nutrients. *EntoPreneurs* see potential to target athletes in need of high protein intake. Regarding therapeutic food, they have the potential to

[28] As with the report published by Persistence Market Research in 2016, the price for the report published by Global Market Insights in 2016 also costs US 4.500 Dollar and could therefore not be fully accessed. The information of this report were extracted from a sample report.

focus on consumers suffering from specific nutrient deficiencies such as iron deficiency.

The description as wellness food leads back to the approach of the traditional Asian medicine, which assigns health benefits to insects as described earlier (see section 3.3.5). For instance, silkworms and bumblebees seem to consist of bioactive proteins and peptides – antimicrobial substances - which exhibit significant antioxidant capacity as well as antimicrobial or antibacterial functions. Healing potential is also assigned to the fatty acids in mealworm larvae, which can alleviate Alzheimer's disease (Sun-Waterhouse et al., 2016).

Cultural traits which lead to rejecting insects as food will require efforts to convince future consumers. However, the extraction of various nutrients and bio-actives from edible insects for dietary purposes is an approach with relatively high consumer acceptance (e.g., protein and oil from insects).

Pioneering start-ups contribute to overcoming this cultural hurdle. Among them are Bugfoundation (Germany), Edible Unique, Entomofarms, Exo (all USA) and Insectubator/ Swarm Protein (Germany). More than that, for this purpose, the 'International ENTOpreneurs Community' brought to life the World Edible Insect Day (WEID) which is set on October 23rd. Its mission is to promote insect-eating in Europe, North America, and Australia.

For now, in western countries, insects as human food are a niche phenomenon. Notwithstanding the hurdles to become accepted among consumers, it can be expected that this trend will further develop. Global Market Insights (2016) concluded that the "Global edible insect market size would exceed 522 million US dollar [485 million Euro] in sales by 2023, with estimated gains at 42 percent CAGR [Compound Annual Growth Rate]."

In fact, insects are considered food for more far-reaching purposes such as space travel. The company HiProMine is designing a bioreactor suitable for manned deep space missions and sustaining human habitats on other planets (Krywko, 2016). This idea is not new. Already in 1983, Robert Kok proposed to use sparkling beetles for space traveling. He developed a rearing facility for insect farming so that insects could be reared in space and found that "such farms can be easily incorporated into an environment having a high volumetric population density such as a spaceship or a domed megalopolis" (Kok, 1983).

The latter solution approach was picked up by two architects to develop sustainable city concepts. The project Belatchew, for instance, developed a concept called "insect city" where insects are reared on organic waste and are then used as food resources. Intriguingly, the architects also included the ecosystem services of pollination by bees into their concept. Similar to the Belatchew concept which was developed for the city of Stockholm, the architect Jacob Dzamba (University of Toronto) developed the Third Millennium Farming (3MF) concept, which aspires to a similar solution.

10.9_PREPARED ANIMAL FEEDS

Insects are suitable for pet food (10.92.10), as feed for several farm animals (10.91.10), and as aquaculture feed. Insects as pet food are traditionally used for aquarium fish and reptiles. In the future, however, insects are also targeted for the dog and cat food market. Regarding farm animals, insects are already used for aquaculture and in animal feed for poultry in many parts of the world (Van Huis et al., 2013). From 2017, certain insects are allowed to be fed to fish from aquaculture in the European Union, and it is expected that by 2020, insects become a feed source for chicken and pigs.

NUTRITIONAL VALUE FOR FARM ANIMALS AND PETS

As with insects as food, the nutritional profile of insects (high-quality protein and high protein quantity content, rich minerals and vitamin content and very good lipids quality) converts them into a promising substitute and complement for conventional feedstuff for animals, especially for fishmeal, fish oil and – perhaps - soy[29]. Beyond the nutritional benefits, it is currently investigated to which extent insects possess functional properties, for example, due to the chitinous exoskeleton.

In fact, chitin seems to play an important role when it comes to animal health.[30] A study conducted by Bovera et al. (2015) indicates that insect meal (mealworm *Tenebrio molitor)* can completely substitute soybean meal in chicken feed. Apart from the fact that insects are a natural diet for chicken, the research suggested that the chicken developed a better bacteria resistance and immune response when fed with insects, probably due to the prebiotic effects of chitin. Chitin also appears to have antifungal and antimicrobial properties and can restore the compositional balance of the gut. Hence, it might decrease the need for antibiotics (Bovera et al., 2015, Henry et al., 2015).

Furthermore, insects can thrive in manure and organic waste such as black soldier fly larvae and common housefly larvae. They likely produce antibacterial substances to protect themselves from microbial infections. These substances are also known as *peptides* and might also be functional for pigs or poultry (Veldkamp and Bosch, 2015).

Apart from the mealworm, *Tenebrio molitor,* several other insect species (e.g., termites, locust, grasshoppers and crickets mealworms, Asiatic rhinoceros beetles, palm weevil) are considered as a source of feed. However, for the industrial production in the western world the mealworm, *Tenebrio molitor*, the black soldier fly, *Hermetia illucens*, the silkworm, *Bombyx mori*, and the common housefly, *Musca domestica*, are identified as most promising insects. These species are receiving increasing attention especially because they have the potential to valorize organic waste – in addition

[29] The price of soya was 328,38 Euro per metric ton in 2016. This low price makes it hard for insect producers to compete with the price. Fish meal prices however reached 1.215,92 Euro per metric ton in 2016 which allows for a larger margin of insect producers to compete. (FAOSTAT, 2016)

[30] Currently, there exist no internationally accepted and validated procedure to quantify or characterize chitin, which is required to gain more insight in the nutritional properties of chitin in insects. (Veldkamp and Bosch, 2015)

to their ability to adapt to industrial rearing systems and their nutritional profile (Bovera et al., 2015, Veldkamp and Bosch, 2015).

Research on this topic is still ongoing. Its results will be decisive for the successful introduction of insects as feed on the market.

DEVELOPMENT OF INSECTS AS ANIMAL FEED

The development of the animal feed sector is currently limited due to lack of knowledge on the effect of insects as feed. Numerous research projects (e.g., BioConVal, PROteINSECT, Project Desirable, InnSecta) have been established to understand the potential better and transfer knowledge and expertise between developing countries and European feed producers.

The need for alternative feed sources, however, is huge. Increasing wealth in developing countries is already leading to increased consumption of meat, which in turn leads to an increased demand for protein such as fishmeal and soya. Figure 22 depicts the importance of finding substitutes. It shows that feedstuff prices, in particular, soybean meal and fishmeal fluctuate disproportionately as compared to the increase of livestock production.

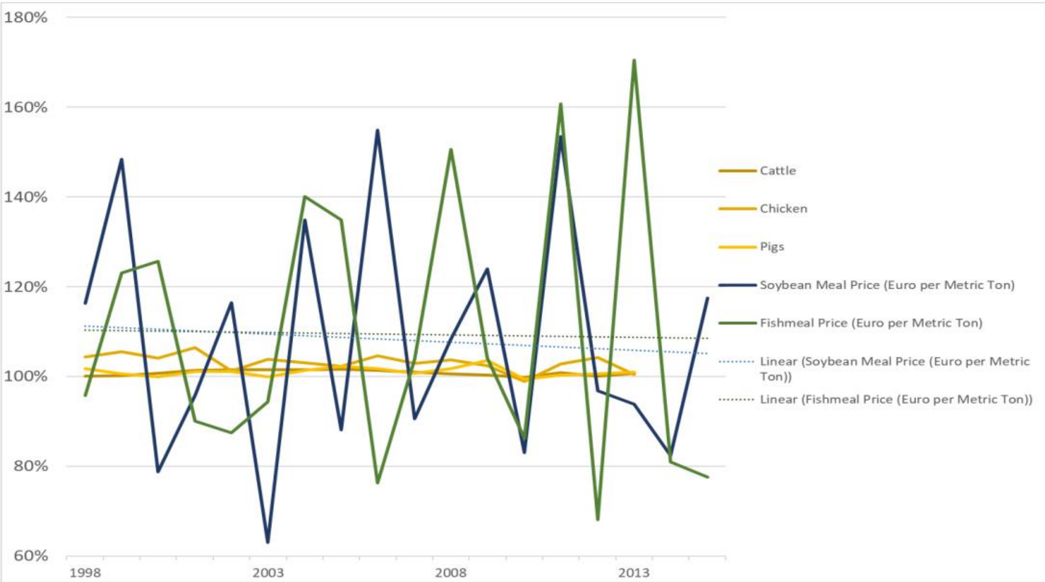

Figure 22: Farm Animal Production compared to Animal Feed Price Change 1998 – 2014
Source: (FAOSTAT, 2016) and Index Mundi

The International Feed Industry Federation calculated that for the year 2015, compound feed production reached close to 1 billion tons worldwide and predicted that demand continues to rise. This trend poses severe challenges to the global capacity to provide enough animal feed because the capacity is constrained by agricultural land and other production factors such as water and ocean fish. Globally, the land availability for soy cultivation is limited, and marine overexploitation has reduced the abundance of small pelagic forage fish from which fishmeal and fish oil are derived. The growing scarcity of resources to produce animal feed has contributed to the immense price fluctuation. At present, animal feed already represents 60 to 70 percent of production costs in farm animals (Veldkamp and Bosch, 2015) and 40 to 70 percent of the production costs of aquaculture fish (Henry et al., 2015). Thus, limited resources restrain this growth and inevitably require alternative sources to satisfy the demand.

The inclusion of insects as a feed commodity will open a huge market and enter into competition with fishmeal and soy meal producers. Volume-wise, pigs remain the second most (900 million animals in 2014) and chicken the third most traded animals (20 million animals in 2014), and aquaculture is the fastest-growing food sector. Hence, the introduction of insects into farming is not only an environmental issue, but also of strategic importance for economic reasons.

A market study from the Netherlands shows that prices of insects are not yet competitive with conventional feed (see Table 3) and vary depending on the insect species (Siriamornpun and Thammapat, 2008).

Table 3: Cost Competitiveness of Insect Protein Compared to Conventional Protein

Protein Source	Raw material prices (humid)	Price of the meal	Protein content of the dry matter	Protein price of dry matter
Yellow mealworm	€ 4,75/kg	€ 15,-/kg	0,86	€9,50/kg
Black Soldier Fly	€ 2,- à € 3,-/kg	€ 3,- to € 9,-/kg	0,63	€ 5,00 - € 10,-/kg
Crickets	€ 30,-/kg	€ 140,-/kg	0,6	€ 233,-/kg
Fish meal	n.d.	€ 1,54/kg	0,65	€ 2,37/kg
High quality soybean meal extract	n.d.	€ 3,67/kg	0,62	€ 5,90/kg
Soybean meal	n.d.	€ 0,7/ kg	0,45	€ 0,82/ kg

Source: (ABN and AMRO, 2016)

To convert insect feed into a competitive commodity, insect producers are currently optimizing processes and upscaling production. To leverage labor productivity, insect producers that aspire for large-scale production such as Enterra (Canada), HiProMine (Poland), and Ynsect (France) use a high level of automation and mechanization. For instance, HiProMines' factory is automated and predominantly controlled by robots. All of the processes and equipment can be controlled remotely by using software (Krywko, 2016).

In addition, marketing strategies can be used to make the products more appealing. While this varies depending on the customers, Veldkamp and Bosch (2015; p. 49) indicate that organic farmers in particular may show interest in feeding insects to the animals. This approach can increase the sustainability of their farms because originally insects are a natural food source for the domesticated animals. Regarding insects as feed in aquaculture, experts expect that during the initial market development stage, insects will be a "'specialty ingredient' […] only used for high-end salmon diets" (Pezzato, 2016).

13.10.4 _SILK YARN AND YARN SPUN FROM SILK WASTE

As mentioned earlier, silk is the byproduct of the cocooning of the silkworm – mostly *Bombyx mori*. It is a natural protein fiber, which is used for versatile industrial and commercial purposes. It is a valued fabric used in textiles, for medical purposes such as surgical sutures, in cosmetic products such as makeup or shampoo, and for decoration purposes such as rugs, or wall hangings.

20.12.22_DYES AND PIGMENTS: CARMINE

Another ancient insect-based resource is carminic acid, which has been used for hundreds of years as a natural dye for both clothing and food (Markus, 2014). At first sight, the lac bug or scale insect from which carmine is extracted looks unspectacular – being a fluffy dot on the cactus. Carminic acid or carmine – the *hemolymph* or insect blood stems from the (crushed) cochineal scale insects (family Kerriidae). Specifically, it stems from *Dactylopius coccus*, *Kermes vermilio,* and *Porphyrophora apolonica,* which live on cactus and can be found in warmer hemispheres. The latter two species originate from Europe while the first one, *Dactylopius occus,* stems from Latin America.

It was only in the 16th century that the Latin American species was preferred for trade as the color is more intensive compared to the European species'. During this period, it was among the most important export goods from the American continent of the Spanish Empire together with silver. This valuable colorant was used for expensive fabrics, but also as painting colors by painters such as Tintoretto, Rubens, and Velázquez. (Markus, 2014)

During the 20th century, carmine was commonly replaced by synthetic aniline dyes – a fate that also hit other insect-based products. Similar to silk, the production of carmine depends on highly laborious production processes with primarily manual labor. However, until today, carmine remains a valid and widely used natural alternative to synthetics due to the adverse reactions of people against them.

Nowadays, production mainly takes place in Mexico, Peru and the Canary Islands (Spain). The dependence on manual labor keeps costs high reaching prices of 200 Euros (220 US dollars) per kilogram. Carmine can be found in food products such as frozen meat and fish, different types of beverages, dairy products, sweets, syrups, and ketchup as well as in cosmetic products such as lipstick. In the EU, it is also recognized as the colorant E120. Carmine suppliers have registered an increased demand from the food industry in Europe due to the overall trend towards natural ingredients (Heller, 2010) (Melton Hutto, 2015).

20.15.80 _ANIMAL OR VEGETABLE FERTILISERS: INSECT FRASS

Insect frass or manure or cast is a natural byproduct of insect rearing. The benefits of it are not new. However, the focus primarily lay on worm casts originating from earthworms (e.g., UNCO, Organic Solutions (both US) and Albfertil Naturdünger GmbH (Germany)). In China and other sericulture (silk producing) countries, the insect frass of silkworms is commonly used as fertilizer for agricultural fields. With the expansion of insect farms in the western world, these byproducts are gaining commercial relevance.

Fertilizers can contain 16 nutrients – all nutrients that plants need to thrive. Specifically, Calcium (Ca), Sulphur (S) and Magnesium (Mg), Zinc (Zn), Copper (Cu), Iron (Fe), Boron (B) Molybdenum (Mo) and Nitrogen (N), Phosphorus (P), Potassium (K).

The latter three nutrients are the basic components. Nitrogen (N) is responsible for plant growth, Phosphorus (P) is needed for flowering and fruit formation, and Potassium (K) is needed for the general well-being and resilience of the plant.

According to Ycera Ltd. (2014) (China), its ‘Supercast’ contains 14 out of these 16 nutrients, and the company AgriProtein sells ‘MagSoil’, which contains 11 nutrients (see Figure 23). The comparison shows that the nutrient content of insect frass is not always homogeneous. Thus, there still is a research gap regarding this topic which Wageningen University has recently been addressing (Edible Insect Seminar, December 2016).

Supercast’s Ingredient
超卡士之有效成份

氮:磷:钾	N:P:K ratio	3:4:3	
有机质	Organic Matter	58.9	%
蛋白质	Protein	17.5	%
氯	Chlorine (Cl)	0.2	%
水份	Moistures	< 9	%
其他	Others	4.63	%
碳／氮比	C/N Ratio :	16.7	
酸碱度	pH value :	5.6 - 6.3	
微量元素	Trace Elements		
钙	Calcium (Ca)	6140	ppm
硫	Sulphur (S)	2380	ppm
镁	Magnesium (Mg)	5990	ppm
锰	Manganese (Mn)	216	ppm
铁	Iron (Fe)	292	ppm
铜	Copper (Cu)	14.2	ppm
锌	Zinc (Zn)	102	ppm

ppm=parts per million=mg/kg= 克/公斤

AgriProtin: MagSoil

N (%)	P (%)	K (%)	Ca (mg/kg)	Mg (mg/kg)
3.6	1.6	1.4	1.7	0.3

pH	EC	H^2O	Ash	C	C:N
6.9	21	24.1	21	40	16:1
S (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
355	241.6	6286	11.3	78.2	12.2

Figure 23: Insect Frass Composition
Source: (Ycera Ltd., 2014, AgriProtein, 2017)

Despite this quality concerns, those products that are on the market are advertised for multiple benefits: it supports sustainable agriculture activities and soil rejuvenation by fostering the activity of naturally occurring soil organisms such as earthworms, fungi, and micro-organisms. It naturally contains chitin, which originates from the molts, which acts as a natural biological pesticide for plants against pests such as grey mold and powdery mildew because it activates an autoimmune response in plants (Ycera Ltd., 2014, Organic Solution, 2015).

Other companies also recognized this market opportunity. Among them are Beta Hatch (US), Entocycle (UK), Entologics Nutrientes Sustentáveis Ltda. (Brazil), Protix (Netherlands), Bioflytech (Spain), Enterra Feed (Canada) and Ynsect (France). All of these companies (plan to) sell this (waste) byproduct as one out of a broader portfolio of products obtained from insect rearing and processing.

The successful positioning on the market is indeed a promising opportunity because the market for fertilizers is expanding. Furthermore, insect frass represents a sustainable solution to ecological problems related to the soil. Hence, those products have shown to be particularly attractive to environmentally conscious consumers such as organic growers.

20.30.22_ PAINTS, VARNISHES, AND SIMILAR COATINGS, PRINTING INK AND MASTICS: SHELLAC

Shellac is another product obtained from the cochineal scale insects or lac insects but the family is Lacciferidae, and it is precisely the species *Kerria lacca* und *Laccifer lacca*, which are economically relevant. Shellac is a natural resin obtained from the fluid secretion of the female scale insects. When dry, it becomes a resin that fits versatile purposes because shellac is thermoplastic, able of film formation, is little sensitive to organic solvents, is easily adhesive to a number of surfaces and has good electric characteristics (Berenbaum, 1997).

In the industry, it is used as a resin, coloring agent, for drug coating, varnish and moisture protector. It is applied for taste masking and moisture protection of drugs, in the food industry, e.g., as coatings for chocolate candies, and as a surface treatment for fruits. It is also widely used in natural and conventional cosmetics, e.g., as a brightener for hairspray and nail polish. Moreover, shellac can be used for furniture polish, finish and as wood treatment for textile and wood fabrics. In electronics, it can function as an insulator. Hence, shellac is used in multiple industries, such as the food, pharmaceutical, and cosmetics industry (Stroever Schellack Bremen, 2016).

Lac insects thrive on several host plants which are prominent, e.g., in Indochina, the Philippines, and Sri Lanka. They are semi-cultivated living on trees, where they are harvested during their reproduction season. For this reason, shellac production requires sustainable management techniques. In Kerala, a southern state of India, shellac production is a means to environmental protection (TNN, 2016).

20.59.51_PEPTONES, OTHER PROTEIN SUBSTANCES, AND THEIR DERIVATIVES

Proteins are fundamental building blocks in the Bio-Economy. Apart from being considered an essential source of nutrition, the field of *proteomics* studies the full complement of proteins within an organism and the way they can advance therapeutic treatment such as the treatment of reproductive disorders.

In the subsection of insects as food and feed it became clear that insects contain – depending on their life stage and species – a high percentage of protein, which could be applied for other purposes than as food and feed. Proteins, however, have special functional properties and are therefore promising to be applied in other industries. Hence, proteins based on insects could be used for the generation of high-value proteins and thereby, create opportunities for a viable industrial Bio-Economy.

PROTEINS AS BUILDING BLOCKS FOR THE CHEMICAL INDUSTRY

At the very beginning of the 20th century, proteins had already been the starting point of plastic chemistry. Specifically, casein, a milk protein, was the main constituent of the synthetic material *Galalith*. It was used for knobs, umbrella handles and to isolate electronic installations. However, with the increasing use of petroleum, this synthetic material lost importance. Technological advances in the Bio-Economy (e.g., in Bioinformatics and molecular biology) may revive the use of proteins and make them relevant again.

For industrial applications, the technical properties of proteins are of primary interest. Some proteins are emulsifying as they form foams or bind oil or water. Furthermore, they can be used as paints and varnishes, as adhesives and lubricants, as additives in polymers and as part of cleaning products. If proteins are used for such purposes, they are called *techno-functional proteins* (cf. research alliance: Technofunktionelle Proteine – TeFuProt).Thus, proteins can be transformed into an attractive bio-based raw material for a wide variety of technical applications.

Currently, proteins for the chemical industry receive little publicity. The strategic alliance *TeFuProt* (an acronym for techno-functional proteins) aims to change this situation and researches proteins originating from residues of agricultural production. Specifically, it aims to promote proteins for high-quality technical applications such as chemical substances for paints, lacquers, adhesives, building materials, plastics, and films. The research alliance focuses on rape and not on insects. Still, insects can also be researched for potential techno-functional uses in the industry. This is particularly relevant when insects are to be reared on organic side streams such as pig manure and which in turn cannot be used as food or feed.

ENZYMES

Enzymes are proteins that can repeatedly catalyze biochemical reactions without being damaged by those reactions. Examples of enzymes used in the industry are detergents, which can efficiently clean clothes at low temperatures. In food and feed products, they enhance digestion. They are also used for pulp and paper production, for the production of pharmaceuticals, and for the production of chemicals (OECD, 2009a).

Obtaining enzymes from insects is of particular interest because insects are the most diverse group of organisms on Earth, colonizing almost every ecological niche of the planet. To survive in various and sometimes extreme habitats, insects have established diverse biological and chemical systems. Core components of these biological and chemical systems are enzymes that enable the insects to feed on diverse nutrient sources. They are produced by either the insects themselves (*homologous*), by symbiotic organisms located in the insects' bodies, or their nests (*heterologous*).

Currently, research, particularly around Yellow Biotechnology, expands the toolbox of enzymes for industrial applications and food and feed industry by including insect enzymes (e.g., peptidases, amylases, lipases) (Mika et al., 2013, Vilcinskas, 2013b). The following example shows the value of the enzymes:

The burying beetle or *Nicrophorus vespilloides* lives on mouse carcasses. It can sense and locate the carcasses over a distance of several miles and bury them. The Bioresources group of the Yellow Biotechnology discovered several preservatives in burying beetle saliva stemming from the secreting enzymes in its saliva, which prevent microbial degradation of the carcass until it is used to feed the beetle hatch. These enzymes are tested for potential industrial applications in the degradation of organic substances and can be used to preserve food as well as prevent microbial degradation (Fischer et al., 2011).

Another prominent example of using insect-based enzymes is the maggot therapy. This therapy uses maggots of the common bluebottle or meat fly (genus *Lucilia*) to feed on wound tissues. While feeding on them, the maggots produce enzymes in their gut (Hardouin, 2005). These enzymes have an antibiotic effect and even accelerate the healing process. Despite its benefits, this approach generally creates repulse by patients. Therefore, the Yellow Biotechnology is advancing the maggot therapy from molecular-level by isolating the enzymes responsible for the wound healing process. Once isolated, it is the overall objective to develop hygienic patches that contain the enzymes.

The third example is feed enzymes. Feed enzymes are employed to improve the availability of certain nutrients or to improve the digestion and can thereby help reduce feed costs. According to Koeleman (2016a), the global feed enzyme market is projected to grow by 7.3 percent from 2015 to 2020.

CHITIN

Chitin was already mentioned for its benefits in animal feeds and as part of insect-based fertilizer. Besides cellulose, chitin is the second most important natural *biopolymer* in the world. Biopolymers are chemical substances composed of macromolecules such as proteins, which then form a material and occur in nature. Silk and hair are also biopolymers composed of proteins. Chitin is found in the shell of marine crustaceans, such as shrimps and crabs, in the exoskeleton of insects and fungi.

The interest in the commercial applications of chitin propagated in the 1930s and 1940s but was then substituted by synthetic polymers. It again became relevant in the 1970s when regulations limited the dumping of untreated shellfish waste in coastal waters. Nowadays, chitin can easily be extracted from crab, lobster and prawn shells using solvents, thereby allowing chitin to become an economical way to comply with the regulations (Stoye, 2013).

It has versatile biological and chemical properties, which allow for their versatile use. It is among others biodegradable to normal body constituents, safe and non-toxic and shows antimicrobial activity (Liu, n.d.). Therefore, it can be used for industrial applications such as pharmaceutical and cosmetic products to water treatment, soil improvement, and plant protection, but also for biomedical applications such as human tissue engineering and wound healing (Dutta et al., 2004).

The total annual world production of purified chitin obtained from byproducts of the seafood industry is about 1600 tons, with Japan and USA being the leading producers. The European market is increasing steadily. However, chitin and chitosan have to be imported to Europe for industrial application. It was expected that the global market for chitin and its derivatives would reach 58 billion Euros (63 billion US dollars) in 2015 (Stoye, 2013). Several market studies indicate that the market for chitin will grow, e.g., for end-user applications and surging demand from agrochemicals and healthcare sectors are expected to drive the chitin market (Global Industry Analysts Inc., 2016, Future Market Insight, 2017)[31].

Currently, the companies Proti-Farm and Protix Biosystems BV (both Netherlands) are selling insect-based chitin. Proti-Farm focuses on chitin and derivatives for soil

[31] The reports are high priced at 4.950 US dollars and 5.000 US dollars, respectively, which is why only the general information was assessed in order to give a general insight on the potential of chitin.

improvement and, Protix Biosystems focuses on applications from bio-coatings to soil improvement additives.

Since 2015, the project ChitoTex (Fraunhofer IGB) studies insect-based chitin as a bioresource for the textile industry. It aims to valorize insect side-products and the application of insect chitin in functional coatings for textile surfaces, especially for technical purposes in home areas, packaging materials, building construction, geotextiles as well as clothing for working and protection. Protix Biosystems is one of the six project leaders.

Another research program is CHITINSECT. It explores the extraction and derivatization of chitin from insects and sustainable applications in agriculture and chemistry. The project leader of the program was the company Millibeter (Belgium). It is doing research and development around the black soldier fly to bio-convert organic waste into proteins, fats, and chitin.

20.59.59 _MISCELLANEOUS OTHER CHEMICAL PRODUCTS AND 21_BASIC PHARMACEUTICAL PRODUCTS AND PHARMACEUTICAL PREPARATIONS

Several research institutes dedicate their effort on revealing the secrets of insects through bioprospecting and the potential to make them useful for humans. Bioprospection in the context of insects focuses on some particularities of specific insects such as those living in adverse habitats. Through this approach, bioactive compounds (i.e., enzymes) can be detected that could be used to develop new drugs and substances for the industry. Most of those research activities are still in their infancy; however, it holds large potential to contribute to greening the chemistry industry and to fight diseases.

Bioactive compounds can originate from their gut and defense mechanisms of insects such as poison or viruses, pheromones. The latter mechanism is already widely utilized among insecticides (20.20 _Pesticides and other agrochemical products). Some insects can produce more than a dozen of substances to protect themselves against enemies. Therefore, they are also recognized as ‘chemical laboratories’ or a pharmacy as Berenbaum (1997) calls them. Some insects store their poison in glands as is the case with the bombardier beetle that ejects boiling water when under attack, in other insects it circulates in their blood converting them into evil-tasting prey.

The fly *Helaeomyia petrolei* lives in crude oil and feeds on organic matter that remains trapped in it. The fly is resistant to about 200,000 heterotrophic bacteria which have been of interest to scientists searching for microorganisms or enzymes that function in an organic solvent environment. The bacteria found in the oil fly larval gut are likely to exhibit pronounced solvent tolerance and may become a future source of industrially useful, solvent-tolerant enzymes (n.d., 1999).

The use of insects, however, goes beyond the ones listed above. The Research Department on Bees and the Environment of the French National Institute on Agronomic Research (INRA) is using the high-developed sense of smell of bees to search for dangerous or illegal objects such as explosives (TNT and DNT) or drugs. To find the desired objects, the bees get trained to smell the explosives and receive sweets as rewards once the objects are found. Whether or not the solution is fully effective is still in its testing phase. One major remaining problem is that bees, unlike dogs, only follow the incentive of the reward. Some of them would abandon the instruction from the dressage already if their search was unsuccessful after one or two intents (Court, 2014).

The examples show that solutions based on insects are extensive. Research advances related to basic and applied research will, i.e., originate from the Yellow Biotechnology research group. Two books provide an overview of the related topics of research: “Yellow Biotechnology I - Insect Biotechnology in Drug Discovery and Preclinical Research” and “Yellow Biotechnology II - Insect Biotechnology in Plant Protection and Industry” (Vilcinskas, 2013a, b).

3.5.3 WATER SUPPLY, SEWERAGE, WASTE MANAGEMENT AND REMEDIATION SERVICES

This CPA group refers to the NACE section Electricity, Gas and Water Supply and comprises activities related to waste treatment, waste management, and remediation services. In this section, however, the focus lies on the role of insects as bio-converters of waste streams. This ecosystem service can be monetized, as is occurring with pollination and natural pest control. In that way, insects can become a solution to address the issue of organic waste production.

Organic waste and specifically food waste represents a significant share of the total waste production. Apart from the ethical dilemmas that this loss entails, it represents an economic challenge as well as an environmental and social one: It produces costs related to waste disposal and reduced sales volume. For example, the post-harvest loss in the United States alone totaled an estimated 161.6 billion US dollars (retail prices) in 2010 (Buzby et al., 2014). Furthermore, it produces health risks since once the organic waste reaches landfills, it risks producing groundwater contamination by leachate (Girotto et al., 2015).

Organic waste can be distinguished into hazardous and non-hazardous waste – a distinction that is of particular importance, if waste products are to be reintegrated into the food value chain. Organic waste is produced in each value chain link of the food production (see Figure 24): during farming and animal husbandry activities, during food processing, manufacturing and retailing, at the household level and disposal. However, hazardous waste is produced only during animal husbandry (manure or dung) and becomes available during its disposal (Girotto et al., 2015).

Three organic waste streams can be distinguished:

1. Hazardous organic waste stemming from manure, dung, and other sources
2. Organic waste from lignin-like materials
3. Food waste

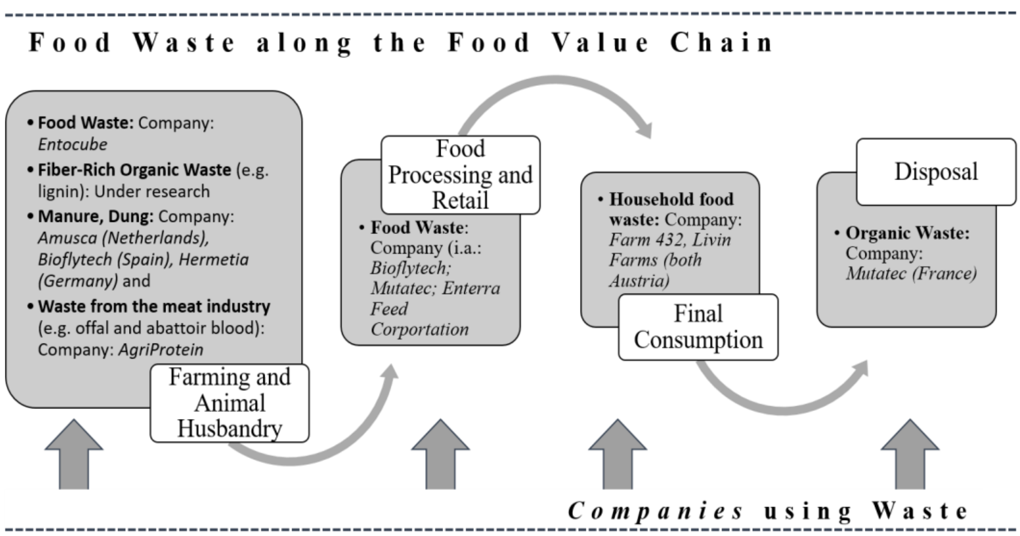

Figure 24: Food Waste along the Food Value Chain and Business Opportunities
Source: Figure based on Girotto et al. (2015).

Manure and dung originating from livestock rearing (1.) represent a severe environmental challenge. It results from the high risk of contaminating soils and surface waters, if manure production exceeds the assimilation capacity of the environment. Manure contains a reservoir of pathogens, parasites and weed seeds and its risks increase with the intensification of livestock husbandry (Chemnitz and Benning, 2014). On the other hand, it also contains phosphorus, nitrogen and potassium – which are the three primary components of fertilizers (cf. p. 95) - which is the reason for liquid manure being commonly sprayed onto fields functioning as fertilizers. Because plants are not adequately absorbing these nutrients, nitrogen and phosphorus are leaking into streams, lakes, and the oceans. In that way, they are severely impacting ecosystems, e.g., by making them homogeneous instead of biodiverse (cf. see research project NITROLIMIT (Germany)). Hence, manure and dung require special waste management techniques.

Organic waste (2.) from lignin-like materials represents the most massive amount of organic waste produced during farming (70 – 80 percent). For example, if corn is used as food (and not for biogas production), then the harvest of a corn plantation focuses on the corn– leaving all plant matter unattractive as well as the cob. The core problem with such plant matter is that lignin-like material is indigestible for most animals[32] and very difficult to degrade. Hence, identifying insects that can process lignin would solve a critical bottleneck in the farming industry.

Food waste (3.) is an organic matter, which is most easily convertible into feedstuff. If the waste is traceable, safe and underlies end-to-end quality control, then it can be used as feedstuff of farm animals. In particular, ‘former foodstuff’ complies with these conditions. Former foodstuff refers to food products that are removed from the human food consumption market by food manufacturers, because of unintentional and often unavoidable production errors. “Examples of former foodstuffs used in animal feed are broken biscuits and chocolates, surplus bread, incorrectly flavored crisps and

[32] Cows can digest lignin but it is this process which produces methane emissions.

breakfast cereals." The challenge that this type of side product faces is that it is still considered as waste according to European Union laws. The European Former Foodstuff Processors Association (in short EFFPA) advocates that former foodstuffs are considered as by-products instead of wastes or residues (Koeleman, 2015).

Insects can be raised on a wide range of foods, including agricultural bio-waste and food wastes, and then be reused as animal feed, food or other purposes.

In this section, it will be explained how insects can help solve waste issues, especially those occurring along the food value chain. While some of the mentioned economic activities are already taking place, others require further research to determine their potential and identify the business opportunity.

38.2_WASTE TREATMENT AND DISPOSAL SERVICES

FOOD WASTE

Undoubtedly, the most remarkable services insects can take out are their ability to turn a wide variety of organic waste into high-quality nutrients, namely animal protein and dietary energy. Insects have a high *feed conversion efficiency*, which is the amount of feed needed to increase body mass (Paoletti and Dreon, 2005). Cattle, for example, require 10 kilograms of feed for one kilogram of body weight while crickets require only 1.7 kilograms of feed to gain one kilogram of body weight. The efficiency is gained because insects are *poikilothermic* and do not use their metabolism to maintain their body temperature. Therefore, most of the insect feed is directly converted to body mass (Lindroth, 1993). More than that, only 40 percent of a cows' body weight is used for meat production while in the case of crickets 80 to 100 percent can be used as feed or food (Van Huis et al., 2013). This efficiency may prove key in insects becoming a global source of food and feed.

Insects are able to feed on diverse feed sources spanning from food industry byproducts, agricultural waste and other organic side streams such as compost, pig slurry or manure that humans and traditional livestock cannot digest (Finke, 2013). In particular, as flies, crickets, grasshoppers, and beetles are suitable for feeding on biomass that is not consumable by humans. In that way, insects do not compete with the human food supply as do vertebrate livestock such as cows and chickens.

Several companies have recognized this opportunity already, such as Entologics Nutrientes Sustentáveis Ltda. (Brazil), Albfertil (Germany), and Enterra Feed Corporation (Canada). Most of them address the food sources from the manufacturing and retail sector. Here, they find high and concentrated volumes of food waste by which they can sustain large production capacities and meet economy of scale. More than that, this approach allows achieving endured cost-effectiveness. Furthermore, these companies produce near to zero waste and have a net positive impact because they source organic waste from communities or nearby companies.

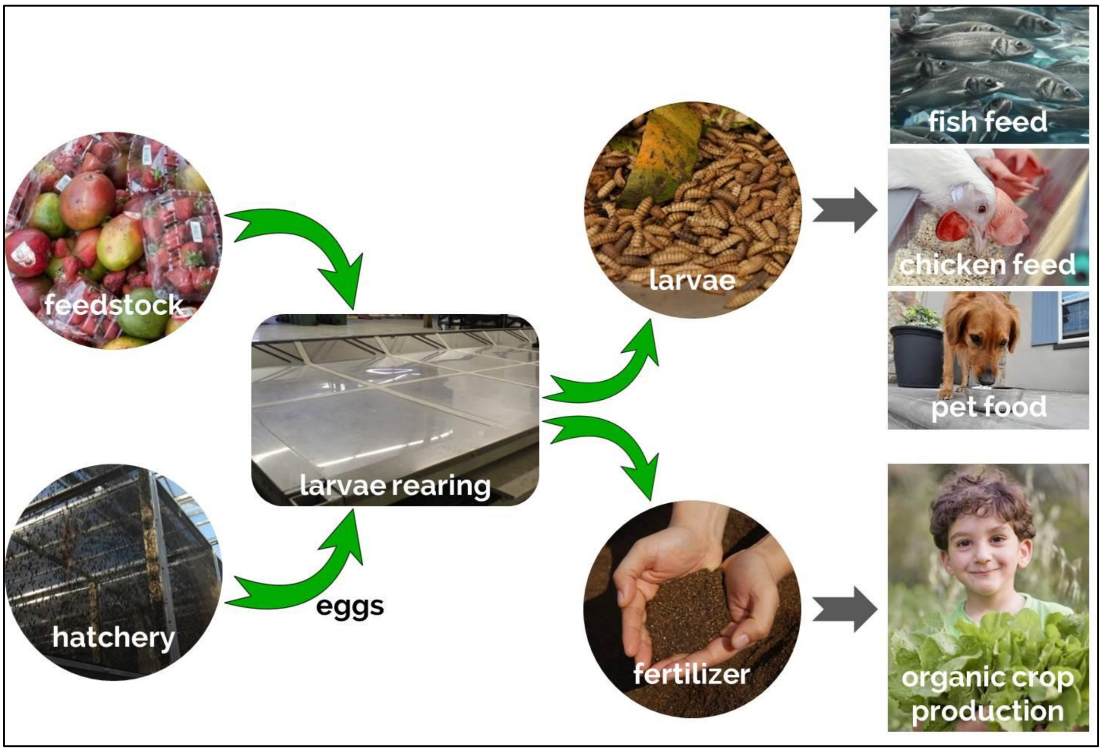

Figure 25: Process from Waste Conversion to Final Products
Source: (Enterra Feed Corporation, 2016)

Enterra for instance, sources its organic residues from grocery stores, farms, greenhouses, and bakeries among others. In that way, the company "closes the loop on food waste" as it states on the webpage and receives low-cost feedstuff. The service of "managing" organic waste is not necessarily monetized. However, depending on the cost of the waste, this service may become an opportunity fore monetization. In any case, the insect feed is safe, while the process is traceable and trackable. Figure 25 shows the value creation process at Enterra.

MANURE, DUNG AND OTHER UNSAFE WASTE

Some insect species are *coprophagous,* which means that they feed on feces and thereby, degrade and transform them into biomass. Intriguingly, the residual organic matter that was not assimilated by their body is also decomposed and converted into compost and plants and other organisms are able to access the nutrients (see p. 66). Furthermore, these species have several biologically active substances, such as antimicrobial peptides, lectin, and chitin which reduce the number of pathogens of this biomass.

The diversity of insects that take out this function is high, including members of the family of butterflies (Lepidoptera), flies (Diptera), bees and wasps (Hymenoptera), and beetles (Coleoptera) (Sun-Waterhouse et al., 2016). However, particularly the common house fly, *Musca domestica,* and the black soldier fly, *Hermetia illucens,* are the most researched insects as solutions to process manure from livestock raised at industrial scale.

Several research projects dealt with this innovative idea. For example, the EU project ECODIPTERA (Spain, Slovakia) and the M2LARV-research program (Belgium) were dedicated to the treatment of pig manure in situ at the hog farm. Another project – BIOCONVAL - was carried out by the Danish Technological Institute, which dealt with the conversion of chicken manure by fly larvae.

ECODIPTERA studied the “Implementation of a management model for the ecologically sustainable treatment of pig manure in the Region of Los Serranos, Valencia-Spain.” The project ended with the construction of pilot plants in Spain and Slovakia that were capable of processing up to 440 kilos of pig waste per week at the hog farms. Thereby, the project contributed to developing localized technological solutions which at the same time, significantly reduced waste at the farm level.

Results from the ECODIPTERA projects further showed that their larvae (black soldier fly, *Hermetia illucens*, and housefly, *Musca domestica*) could rapidly (approx. 7–10 days) transform low-quality organic waste into good quality fertilizer and new biomass in the form of larvae or pupae. In comparison to non-degraded manure, the insects reduced water content and odor (approx. 50 percent) of waste material for disposal. Furthermore, they contributed to reducing nitrogen levels by 30 to 50 percent and phosphorus waste by 61 to 70 percent, and they showed to have a positive effect on reducing pathogens of the manure mass (Cickova et al., 2012, Gobby et al., 2013).

As a result of this bioconversion process, not only the manure is processed into value-added organic matter, but also an abundant amount of insect larvae or prepupae is produced. These fly larvae are rich in proteins (40 percent) and lipids (30 percent).

The potential of using those ecosystem services can be extended to other farm wastes such as abattoir blood and offal – which the company AgriProtein (South Africa) uses - or meat flours, tanned skins, sewage sludge which the company Bioflytech (2013) uses. Additionally, slurry, old fryer grease, and silage waste can be converted by them. Hence, insects can be a solution to overcome severe environmental problem originating from hazardous products.

In countries, with stringent environmental legislation, the recycling of toxic waste is a considerable cost factor for the polluter. Livestock farmers, for instance, have to pay for the recycling of the manure. Small farmers especially have economic limitations that inhibit them from applying modern recommended manure management technologies such as liquid and solid fractions separation, aerobic or anaerobic digestion, composting and fermentation (Cickova et al., 2012). More than that, these techniques also have toxic effects. Therefore, new and affordable technologies are needed to solve this environmental problem.

Insects seem to be an affordable and efficient solution to address this issue and solve multiple problems at once: conversion of manure, production of value-added biomass in the form of the insect and organic matter, and reduction of pathogens. Even though the insects as bioresources may not comply with the standards of their use them in the food value chain or for the production of pharmaceuticals, the lipids and proteins may be used for industrial applications as described earlier.

ORGANIC WASTE FROM LIGNIN-LIKE MATERIALS

Approximately 75 percent of agricultural biomass consists of lignin or cellulose. These are essential elements of fiber-rich biomass and are widely indigestible for farm animals. For this reason, lignin and cellulose end up as residue. Already Kok (1983) saw the necessity to identify species that are capable of utilizing an inexpensive substrate. It is currently known that bacteria, fungi, and microorganisms degrade lignin very efficiently. Kok (1983) also did a comprehensive research on selecting a species that could be used as a source of food and feed (for spaceship crews), and that would be able to use such cheap substance. He identified the drugstore beetle (family *Stegobiumpaniceum*) as the ideal species. Additionally, other insects such as silkworms, termites, and bark beetles, silverfish, *Lepisma saccarina*, but also the family of *Oecophoridae* and *Tineidae* seem to possess the characteristics to assimilate lignin and cellulose and convert it into biomass. More species could potentially be found on compositing sites.

The insect species that are currently under research as sources for food and feed do not seem to be able to digest lignin-like materials. Due to the large amounts of lignin and cellulose produced in agriculture, these issues should receive more attention.

3.5.4 WHOLESALE AND RETAIL TRADE SERVICES

Insect-based products – in particular insects as food - are already sold through retailers (47.00.24). The company Entosense (US) for instance, promotes "entomophagy for a healthy future" and showcases products based on insects online. Another example is Thailand Unique. Its products range from insect flour, insects as snacks and sweets, and even a starter set for entomophagy. Here, people who want to try entomophagy find a mix of different insects: grasshoppers, mealworms, buffalo worms and others. The complete version of such a starter set comes with a cookery book.

3.5.5 PROFESSIONAL, SCIENTIFIC AND TECHNICAL SERVICES

70.2 _MANAGEMENT CONSULTING SERVICES

Consulting services in the Insect Economy could be identified in relation to agriculture-related ecosystem services such as pest control and insects as food and as feed.

- Insects as food and feed: EntomoAgroindustrial (Spain), 4Ento and Protein Synergy (both Switzerland)
- Knowledge transfer regarding pest management as well as for integrated pest management: e.g., Koppert Biological Systems, BioBee (both Netherlands)
- Production of mass rearing facilities: e.g., Protix Biosystems (Netherlands), Iowa Cricket Farmer (US)
- Food technology: Entomotech (Spain), Little Herds (US)

Entomotech, for instance, is a spin-off of the University of Alicante (Spain). It offers consultation services in diverse fields such as pest management, mass rearing facilities, food technology, and R&D related to insects as bioresources. Protein Synergy focuses primarily on the food and feed sector. It promotes business alliances among companies working within the field of insects for human consumption and animal feed. Furthermore, it conceives and develops market opportunities for edible insects and promotes rearing and processing facilities for these purposes. 4Ento specializes in the trade fairs for insect-based products.

72.1_RESEARCH AND EXPERIMENTAL DEVELOPMENT SERVICES IN NATURAL SCIENCES AND ENGINEERING

This economic activity considers topics related to both the development of originals in biotechnology and to health, environmental, agricultural and other biotechnology. Therefore, these topics are key for the advances of the research breakthroughs originating from the Yellow Biotechnology.

It was already explained that insects could be used as sources of new drugs, e.g., antibiotics. However, their medical use extends well beyond the bioresources and includes their development as preclinical research models, facilitating both the investigation of molecular mechanisms underlying human diseases and the inexpensive and ethical in vivo testing of drugs (Vilcinskas, 2013a).

Blowflies, horseflies, several filth flies, mosquitoes, and the common bed bug, *Cimex lectularius L.*, have been essential for the advancement of medical and veterinary research. Further, insects that are vectors of human and animal pathogens, such as mosquitoes and the tsetse flies, were used to screen chemical compounds for repellency and toxicity, as well as to develop useful formulations of drugs. The most commonly known insect for research purposes is probably the fruit fly, *Drosophila melanogaster*, which became the standard insect model for genetic research (Leppla et al., 2014).

There exist 5000 genomes stemming from insects (Adebiotech, 2014; p. 12). These genes can well be utilized to conduct research on new vaccines, gene therapy and more. For example, the company ExpresS2ion Biotechnologies (France) uses the cells of the fruit fly (Drosophila) to research vaccines against malaria.

By the help of biotechnology, using insects as a source for medicinal substances is likely to become easier. Without the technology, the process has been challenging for multiple reasons: first of all, the successful search for a useful insect is challenging. Secondly, most insects are difficult to find and rear under conditions of captivity. Thirdly, even if a useful species has been identified and successfully bred, it is still demanding to gain a sufficient amount of relevant material. Insects are usually tiny, as are their glands which produce the potentially interesting active compound for research (Piper, 2017).

Still, according to the University of Paris Descartes, there exist vast opportunities, e.g., to analyze the salivary molecules of blood-sucking insects in respect to their effect on vasodilator or anti-inflammatory functions or even the peptides derived from venoms. The peptides from the cockroach species, *Periplaneta Americana*, and the rat tail larvae, *Eristalis tenax* may become a solution to antibiotic resistance. Moreover, the wax moth, *Galeria*, is researched to identify antibacterial substances (peptides) against multi-resistant germs or the Asian ladybird, *Harmonia axyridis*, is researched to develop antibiotics against tuberculosis (Vogel and Vilcinskas, 2013). Hence, there is hope to also develop medications for rare diseases.

A number of companies developed business models to supply the research sector such as Agate Biosciences (France), Eucodis Bioscience (Austria) - which forms part of the aforementioned ChitoTex EU project - and Bioflytech (Spain). The division BioflyLab of the company Bioflytech, for instance, offers research service, development of and assessment for specific projects related to the controlled artificial breeding of flies. It also sells larvae or pupae of several species of flies (*Lucilia sericata, Protophormia terraenovae*, and *Hermetia illucens*) reared in conditions on request.

3.5.6 ARTS, ENTERTAINMENT AND RECREATION SERVICES

The insect-based activities related to arts, entertainment and recreation are anecdotal, but for the sake of completeness, they deserve consideration. In the earlier section on the relation between insects and culture (see 3.3.5), the flea circus was mentioned, which is an activity that is not practiced anymore. However, the gambling tradition with duels between rhinoceros beetles and male crickets still persist.

A more representative industry sector that benefits from insects is tourism. Butterfly farms attract tourists worldwide. Following the same principle as zoological gardens, the aim is to preserve species and turn the encounter with those animals into an experience for people of every age group. Here, they can observe the way they grow and produce the metamorphosis from the pupae into a butterfly. The tourism niche - cultural tourism - can attract tourists by introducing them to customs of indigenous peoples related to insects as food and feed or as traditional medicine (more specifically known as Ethno tourism).

3.5.7 SERVICE OF HOUSEHOLDS, UNDIFFERENTIATED GOODS AND SERVICES PRODUCED BY HOUSEHOLDS FOR OWN USE

Insect rearing, processing as well as sales can be done at household scale. As mentioned already, insect rearing is a traditional activity done in many rural households across Asia. For that reason, this activity is promoted as an economic activity that bears the opportunity of poverty alleviation and promotes gender equality because it can be done by women or children. In fact, it can be considered a ‘prosumer’ activity, an activity, where the consumer is at the same time the producer of one or multiple products or services (Paech, 2012).

However, not only in developing countries is insect rearing at household scale an option, but several startups (Livin Farms (mealworm), Farm 432 (black soldier fly), and Third Millennium Farming (crickets)) are pioneering in introducing insect desktop hives that can be used for subsistence.

3.5.8 CONCLUSION

This section aimed at exploring business opportunities based on insects. In order to structure the opportunities, the statistical classification of products by activity in the

European Economic Community (acronym CPA) was used. The list and description of the products of economic activities (CPA) produced in the Insect Economy are extensive.

In total, 7 CPA sections and 25 subcategories could be covered (see Figure 26). The most noticeable CPA sections are Products of Agriculture and Fishing, Manufactured Products and Water Supply, Sewage; Waste Management and Remediation Services. The scope and scale of these opportunities justifies the introduction of the term Insect Economy introduced at the beginning of Chapter 3.

Some products and services in the Insect Economy are used since antiquity such as products obtained from honeybees or silkworms. Products related to these insects have been assigned a separate CPA code. Others receive new impetus such as proteins. Biotechnology facilitates the use of these organic constituents for diverse pur-

Products of Agriculture and Fishing

- 01.49.19 _Other farmed animals , live; *e.g. crickets, grasshoppers, mealworm*
- 01.49.21 _Natural honey
- 01.49.24 _Edible products of farm animal origin; *e.g.* royal jelly, pollen, propolis
- 01.49.25 _Silk-worm cocoons suitable for reeling
- 01.49.26 _Insect waxes and spermaceti; *e.g. honey bee way*
- 01.61.10 _Support services to crop production; *e.g. pest control, for agriculture, pollination*

Manufactured Products

- 10.41.19_Other animal fats and oils and their fractions; *e.g. as ingredient for compound feed, industrial oil, substitute for palm oil*
- 10.89.19_Miscellaneous food products; *e.g. insects as ingredients for pasta and functional, therapeutic or wellness food*
- 10.9_Prepared animal feed; , *e.g. for reptiles, dogs, and zoo animals* and *black soldier fly larvae as substitute for fish meal for farm animals*
- 13.10.4 _Silk yarn and yarn spun from silk waste
- 20.12.22_Dyes and pigments; *e.g. Carmine*
- 20.15.80 _Animal or vegetable fertilizers; *Insect frass*
- 20.30.22 _Paints, varnishes and similar coatings, printing ink and mastics; *Shellac*
- 20.59.51_Peptones, other protein substances and their derivatives; *e.g. Proteins, chitin, Enzymes for food or feed industry*
- 20.59.59 _Miscellaneous other chemical products*; insects as resources for bioprospecting* and 21_Basic Pharmaceutical Products and Pharmaceutical Preparations; e.g., *Bioactive compounds that originate from their gut and defense mechanisms such as poison or viruses, pheromones*

Water Supply; Sewerage; Waste Management and Remediation Services

- 37.00.11 _Sewage removal and treatment services; e.g. bioconversion *sewage sludge, manure and dung*
- 38.21.10_Non-hazardous waste treatment for final disposal services*; e.g. bioconversion of food waste*
- 38.22.19_Other hazardous waste treatment service*; e.g. bioconversion of abattoir blood and offal, slurry, old fryer grease and silage waste*

Other Sectors

- Wholesale and Retail Trade Services
- Professional, Scientific and Technical Services
- Arts, Entertainment and Recreation Services
- Service of Households; Undifferentiated Goods and Services produced by households own use.

Figure 26: Overview of CPAs in the Insect Economy

poses. Thus, the Insect Economy has existed for a long time.

However, it is gaining renewed momentum fueled by research advances in applied entomology and by opportunities emerging due to global challenges such as resource scarcity and food insecurity. Therefore, the Insect Economy entails traditional products and services and novel value proposition fueled by the generated know-how and technology.

It could further be observed that the activities in the Insect Economy take place globally. The literature review, as well as the search for businesses in the field suggest that particularly Asia (China, Thailand, Malaysia, and Korea), Europe and the United States are leading both in terms of traditionally using insects and regarding applying biotechnology.

The CPAs also showed that insect-based products could be found in the Business to Business (B2B) and Business to Consumer (B2C) markets. However, insects in B2C markets are so far less representative as long as they are not consumed as food. Insects as production factors (B2B) show a broader scope of opportunities as opposed to consumer markets. There are opportunities to use insects as commodities, e.g., as feed, feed supplement or as a source of raw materials such as lipids, proteins, and chitin for various industrial purposes.

While some insect-based products require little technology such as beekeeping, silk production, and shellac and carmine extraction; other products require highly technologized processes such as extraction of peptides for the production of pharmaceuticals. Both approaches situate the Insect Economy into the Bio-Economy.

3.6 MORPHOLOGY OF THE INSECT ECONOMY

The morphology aims to characterize the Insect Economy. The structure of the morphology is divided into *dimensions* and its respective *features,* whereas the dimensions are divided into overall categories. These categories are the *insect* as a novel resource, *economy,* and *sustainability*. This section lists justifies and describes the features.

3.6.1 DIMENSION: INSECTS

INSECT ORDER

Researchers have identified 39 insect orders. Six insect orders represent half of the diversity among insect species. Those are: beetles (*Coleoptera*; ~ 400.000 species); flies and mosquitos (*Diptera; ~ 160.591 species*); butterflies and moths (*Lepidoptera*; ~ 1158.570 species) and wasps, ants and bees (*Hymenoptera*; ~ 120.000 species); true bugs (*Hemiptera*; *~ 104.165 species*) and grasshoppers and crickets (*Orthoptera*; *~ 24.481 species*) (Zhang, 2013). These dominant orders are listed features in the morphology. The other 33 insect orders are represented as “others.” The whole list of insect orders is available in Appendix 1.

ECOSYSTEM SERVICES

Insects perform valuable ecosystem services. These are *supporting services*, *provisioning services*, *regulating services*, and *cultural services* (see 3.3.3). Table 4 lists the ecosystem services provided by insects.

Table 4: Ecosystem Services provided by Insects

Type of Ecosystem Services	Example of Ecosystem Services provided by Insects
Supporting Services … which are necessary for the production of all ecosystem services	• Distribution of organic material within the soil by ants and termites • Decomposition of organic matter by dung beetles which decompose dung, and flies and carrion beetles which feed on dead animals, and termites process large amounts of wood and leaves.

Provisioning services
… which englobe products or services that humans rely on
	• Physical Insect
	  • Whole insect
	  • Protein
	  • Oil
	  • Carmine
	  • Chitin
	  • Genetic material of insects (e.g., peptides)
	  • Active compounds of insects (cellulase, chitosan)
	  • Body parts
	  • Insects in combination with other elements (bacteria).
	• Byproducts
	  • Honey, Royal Jelly, Pollen, Wax, Propolis
	  • Shellac
	  • Silk
	  • Insect frass
	  • Insect eggs

Regulating services … which are vital for the functioning of the ecosystems	• Natural pest control • Bioindicators • Bioremediation • Pollination

Cultural Services
… which are non-material benefits
	• Aesthetic and recreational value, e.g.,
	  • Butterfly farms
	  • Insects for fishing
	• Inspiration for biomimicry
	• Object of amusement (e.g., flea circus, insect duels)
	• Source of forensic information

REARING PRACTICES

Insects can be reared in *controlled environments*; they can be *semi-cultivated* or *captured in the wild*. While rearing practices in controlled environments are more adapted to industrial processes, semi-cultivation and wild harvesting are common in developing countries such as in Uganda and Thailand. The aspect of rearing practices were mentioned in multiple subsections of 3.3.3 and 3.5.

APPLIED RESEARCH ABOUT INSECTS

Entomology is the field of research dedicated to insects, and it is increasingly used to solve practical problems. Thus, it is expanding from the basic science to become an applied science. Applied research is a fundamental source to create new knowledge and therefore, a primary source of opportunities (Eckhardt and Shane, 2003). The fields of applied research related to insects are listed Table 5. More details can be found under heading 3.4.

Table 5: Applied Research related to Insects as Biological Resources

Applied Research about Insects	Description and Sources of Information
Forensic Entomology	… studies insects feeding on corpses and are a tool in criminal investigations. • Source: e.g., • Amendt, J., et al. (2004). "Forensic entomology." Naturwissenschaften 91(2): 51-65. • Amendt, J., et al. (2011). "Forensic entomology: applications and limitations." Forensic Science, Medicine, and Pathology 7(4): 379-392.
Economic Entomology	… studies arthropods about plant disease, insecticide resistance, and resistance management; …. Studies biological and microbial control as well as biological pest control • Source: e.g., International Journal of Industrial Entomology (ISSN 1598-3579)
Medical Entomology	… studies insects about public and animal health. It is particularly concerned with urban and rural pests as well as the diseases that some insects carry.
Applied Entomology	… studies entomology in a wider context, including molecular biology, environmental science, physiology, ecology, ethology, taxonomy, and toxicology. It examines insect pests, animal pests, natural enemies, beneficial insects, beneficial animals, agricultural chemicals and more. • Source: e.g., Journal of Applied Entomology and Zoology; ISSN: 0003-6862; or Journal of Applied Entomology; ISSN: 1439-0418)
Yellow Biotechnology	… combines entomology with other natural science fields and technology. It uses insects as a biological resource to manipulate them or their molecules, cells, organs or associated microorganisms. … aims to develop knowledge, products, and services for specific *applications in medicine*, *plant protection* or *industry*, hence basic research is jointly developed with industrial partners. • Source: e.g. • Vilcinskas, A. (2013).Yellow Biotechnology I - Insect Biotechnology in Drug Discovery and Preclinical Research. Berlin-Heidelberg, Springer. • Vilcinskas, A. (2013). Yellow Biotechnology II - Insect Biotechnology in Plant Protection and Industry. A. Vilcinskas, Springer.
Industrial Entomology	... studies the advancement of industrial interest and knowledge concerning sericulture, apiculture, entomopathogenic microorganisms, insect cell culture, insect biotechnology, products derived from insects, insect resources, and related fields. • Source: e.g., International Journal of Industrial Entomology or Omkar (ed.) 2017: Industrial Entomology (ISBN 978-981-10-3304-9))
General Fields of Research that include insects	• Agricultural Science • Animal health sciences • Zoology • Forest Science • Insects as Food and Feed • Etc.
Fields of specialization	• (S)Ericultural Sciences – the science of silk

3.6.2 DIMENSION: ECONOMY

PRODUCTS BY ECONOMIC ACTIVITY

This category builds on the statistical classification of products by activity in the European Economic Community (acronym CPA, for a review see page 79). Figure 26 shows that insects, as biological resources are extensively used in the economy. The most noticeable CPA sections are Products of Agriculture, Hunting and Related Services, Manufactured Products and Water Supply, Sewage, Waste Management and Remediation Services. Those are listed as features in the morphology. The remaining are represented under "others." More details can be found under heading 3.5.

INSECTS AS…

The Products by Economic Activity show the industries where insect-based value propositions can be found. However, it is also useful to stress the most dynamically developing value propositions. Those CPAs of most relevance for innovation received proportionally in the descriptive part of insects as bioresources according to CPAs (3.5). Value propositions that stand out are *insects as…: food, feed and pet food, provider for bio-based materials, organic waste converter, natural enemies, and pollinators.* The way these value propositions relate to the Products by Economic Activity is shown in Table 6.

Table 6: Insects as...

Insects as....	Products by Economic Activity
Food	• 10.89.19_Miscellaneous Food Products
Feed and Pet Food	• 10.9_Prepared Animal Feeds
Provider for Diverse Bio-based Materials	• 10.4_Vegetable and animal oils and fats • 20.59.51_Peptones, other Protein Substances and their Derivatives • 20.59.59 _Miscellaneous other Chemical Products • 21_Basic Pharmaceutical Products and Pharmaceutical Preparations
Organic Waste Converter	• 38.2_Waste Treatment and Disposal Services
Natural Enemies and for Pollination	• 01.61.10 _Support Services to Crop Production
Others	• Remaining Products by Economic Activity

BUSINESS MODEL BUILDING BLOCKS

Osterwalder and Pigneur (2010) introduced the business model canvas, which is broadly used in science and business. The canvas, earlier introduced as the ontological type of a business model (see 2.5.2) consists of nine building blocks: Key Partnerships, Key Activities, Key Resources, Value Proposition, Customer Relationship, Channels, Customer Segments and Revenue Stream. The building blocks are included in the morphology.

INNOVATION OBJECT

In section 2.5.1, principal innovation objects were explained. These are products, processes and technology, and business models. These objects are included in the morphology.

TYPE OF CUSTOMER

A dimension that has not been discussed so far is that of the type of customer. Insect-based products can be sold as a commodity to the producers (B2B) such as carmin, shellac, silk and insect-based protein. At the same time, insect-based products can also be sold as a (final) consumer products (B2C) as is the case with insect-based protein bars and honey. Still, the most significant market for insect-based products is the B2B market.

GEOGRAPHIC ORIGIN OF THE BUSINESS

Companies related to insects can be found worldwide. However, their significance changes depending on the geographic regions. The following subsection describes the geographic regions where the products by economic activity can be found and provides an overview in Appendix 5.

PRODUCTS OF AGRICULTURE, HUNTING AND RELATED SERVICES

Insect farming as animal feed, food production and as raw materials for the industry is gaining momentum (01.49.19_Other Farmed Animals_Life). While insect farming is a tradition in many developing countries such as India and Thailand, it is also becoming more and more relevant in industrialized countries. More information on this topic is provided in "Lifecycle of the Industry."

Honey, Royal Jelly, Pollen, Wax, Propolis are all products obtained from honey bees. These products are used worldwide (01.49.21, 24 and 26).

Silk (01.49.25) is a material that is used in versatile ways and is predominately produced in China where 84 percent of the global silk production takes place (170.000t in 2015) according to the International Sericultural Commission (2015). The second largest producer is India (28.523t in 2015), and the third largest producer is Uzbekistan (1.200t in 2015). Those three make up 99 percent of the total production. Full list of silk producers can be found in Appendix 3.

Insects as *natural enemies and pollinators* (01.61.10) are gaining increasing relevance in agriculture (see Appendix 4). Even though no statistics were found depicting the global development of using natural pest control, the empirical database developed by Taponen (2017) is useful. The name of this database is "Entomology Company Database," and it contains companies related to *insects as food and feed* and *insects for pest control and pollination*. It contains 12 companies from Europe, Middle East, North America and Oceania that are dedicated to the latter. The database, however, has no guarantee of completeness, and it can be expected that more companies exist and in further geographic regions.

MANUFACTURED PRODUCTS

There are no official statistics, but according to the research report on "Global and China Shellac Industry 2014 Market Research Report" produced by QYR Research Reports *shellac* production (20.15.80) predominately takes place in India and China.

Carminic acid is used as a natural dye for both clothing and food (Markus, 2014). It stems from the (crushed) cochineal scale insects (family Kerriidae), specifically from *Dactylopius coccus*, *Kermes vermilio* and *Porphyrophora apolonica*, which originate from Europe and Latin America. (20.12.22)

The database elaborated Taponen (2017) listed 290 companies that focus on insects as *food, feed and/or pet food*[33](10.89.19, 10.91.10, 10.92.10). These 290 companies are distributed unevenly across the continents (see Figure 27):[34]

- 6 Companies are located in Africa, e.g., AgriProtein (South Africa), Khepri Innovations (South Africa), Agri-Cycle Namibia (Namibia), Mad'Insect (Madagascar).
- 20 Companies are located in Asia, e.g., HaoCheng (China), Protenga (Singapore), Entobel (Vietnam). (The database, however, neglects the several thousand households that are rearing insects themselves among them in Thailand and Vietnam).
- 11 Companies are located in Australia, e.g., Bugs for Bugs, EntoPro, Goterra.

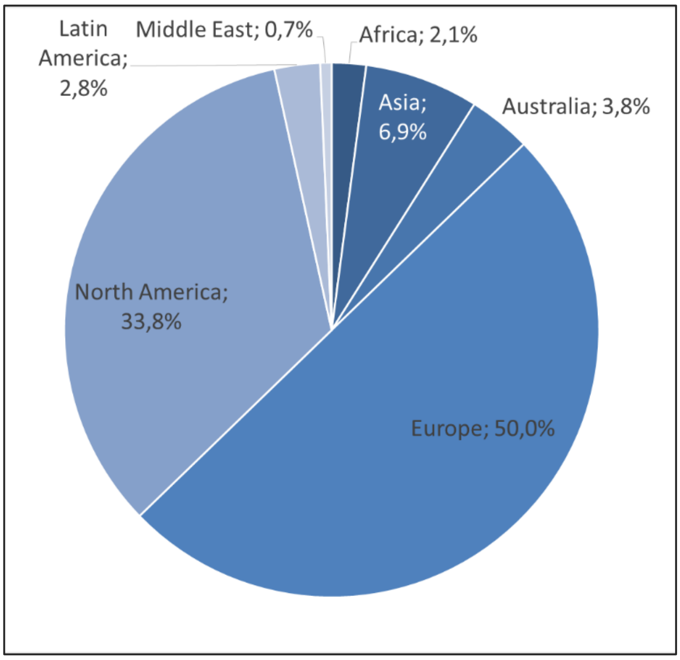

Figure 27: Geographic Distribution of Entomology Companies
Source: Own grapic based on Taponen (2017)

- 145 Companies are located in Europe, e.g., Bugs International (Germany), Entomotech (Spain), Mutatec (France), Essento (Switzerland).
- 98 Companies are located in North America, e.g., Enterra Feed Corporation (Canada), BetaHatch (US) and Next Millennium Farms (US), Tiny Farms (US), ProtaCulture (US).
- 8 Companies are located in Latin America, e.g., Nutrisecta (Brazil), Cricketa (Costa Rica), Entorganics (Colombia).

[33] In this calculation I excluded the firms that farm insects for biocontrol as this is not part of the Entomo-Sector.
[34] The database was introduced in January 2016 and has been updated 58 times since.

- 2 Companies are located in the Middle East. Those are Flying Spark and Hargol FoodTech (all Israel).

This distribution shows that the Insects as food and feed sector is a global phenomenon strongly pushed by consumerist markets, in particular, Europe and North America.

These companies listed may potentially focus on *chitin too* (20.59.51) as a valuable raw material produced as side-product, when separating insects into its fundamental building blocks (protein, lipids). Furthermore, they may use the insect frass as fertilizer (20.15.80).

SEWAGE, WASTE MANAGEMENT AND REMEDIATION SERVICES

Waste management is traditionally done through vermiculture by using earthworms (which pertain to the biological group of Annelids, not Insecta). Additionally, insects are promising the use for this purpose. Several companies have recognized the opportunity to reuse organic waste from food producers or supermarkets such as Entologics Nutrientes Sustentáveis Ltda. (Brazil), and Enterra Feed Corporation (Canada).

Sewage and *remediation services* are separate from waste management. Activities that embrace sewage are, for instance, the conversion of manure. Those activities, however, are not yet practiced by the industry. Remediation services have also not been economically exploited yet.

OTHER SECTORS

Professional, Scientific and Technical Services were identified (and registered in the support database) in the field of:

- Insects for biotechnology (France, Germany, Belgium)
- Insect farming and processing and marketing of insects as food, feed, and pet food (e.g., Spain, Switzerland)
- Insect for natural pest control and pollination (Netherlands)

While all mentioned companies are from Europe, it is highly likely that those services are also available in other geographic regions.

Arts, Entertainment and Recreation Services, are rather anecdotic services. The tradition of using insect for amusement is a tradition that may still be found in Asia. The *aesthetic value of insects*, however, is appreciated worldwide, especially during insect observation in the wild or in insect farms (e.g., butterfly farms). However, the issue of monetizing this aesthetical value seems to be only prevalent for butterfly farms. The beauty of insects plays a role in the attractiveness of natural places in general and can, for instance, be experienced in tourism. Thus, their monetary value is somewhat indirect.

Using insects as *Service of Houshoold, Unidfferentiated Goods and Services produced by Households For Own Use* is a traditional activity done in many rural households in Asia. However, insect rearing at household scale is also an option elsewhere. Moreover, several start-ups (Livin Farms (mealworm), Farm 432 (black soldier fly), EntoCube (crickets); Third Millennium Farming (crickets) are pioneering introduction of insect desktop hives that people can use for subsistence and even for recycling their household waste.

Appendix 5 provides an overview of the geographic origin of businesses according to products obtained from insects.

GEOGRAPHIC SCOPE OF THE BUSINESS ACTIVITIES

Also the geographic scope of business opportunities has not been discussed so far. They are relevant to describe the Insect Economy because the business activities have different geographic scopes. Some activities have a *local* character such as insect rearing for substance where producers sell their surplus at the local markets. In addition, honey production is predominantly a local activity while the distribution might be regional or even international.

Other activities are *national* such as insect collection during high season in Uganda. An example of *regional* business activities is the trade of insects across Thailand, Cambodia, and Vietnam. *International* business activities in the Insect Economy are, for instance, the processing and distribution of silk. Moreover, the emerging businesses around insects as food, feed, and pet food have an international orientation.

MARKETS ACCORDING TO THE HUMAN DEVELOPMENT INDEX

Another perspective on the geographic location of the business is by looking at the degree of human development. The Human Development Index (HDI), distinguishes between:

- *Low Human Development* which is also known as Bottom of the Pyramid (BOP) markets (see 30),
- *Medium Human Development*
- *(Very) High Human Development* which is also known as consumerist markets (see 30).

Differentiating between these groups is fundamental because the demand-related behavior in consumerist, emerging and BOP economies take different shapes. For that reason, value propositions for these markets have to have distinct characteristics depending on the context. While in consumerist economies there is great wealth, in BOP markets people live in severest poverty lacking minimum standards. These differences are particularly important for developing *sustainable* solutions: While it is a challenge to reduce footprints and decouple production and consumption from negative societal impacts in consumerist economies, in BOP markets it is a challenge to increase human development standards and well-being. The ranking of countries according to their HDI is provided on this link[35] (Boons and Lüdeke-Freund, 2013).

LIFECYCLE OF THE INDUSTRY

Another dimension that has not been discussed so far is that of the lifecycle of the industry. The Insect Economy is very heterogeneous from the lifecycle perspective (Johnson et al., 2011). While there are insect-related business opportunities that have been exploited for decades (e.g., shellac) or even centuries (silk and honey production), other business opportunities are recent phenomena (e.g., insects as feed and food) or are rediscovered in the context of the Bio-Economy (e.g., bioprospection for medicine development). It is, therefore, useful to cluster the Insect Economy according to the lifecycle of the different products by economic activity. Appendix 6 depicts more details about the industry lifecycle of the products by economic activity in the Insect Economy.

3.6.3 DIMENSION: SUSTAINABILITY

BUSINESS MODEL INNOVATION GRID: SUSTAINABLE STRATEGIES AND MECHANISMS FOR SUSTAINABLE BUSINESS MODEL INNOVATION

The business model grid is a tool that categorizes groupings of mechanisms that may contribute to building up the business model for sustainability. These categories were denominated *archetypes* (Bocken et al., 2014) and later renamed *sustainable strategies* (Centre for Industrial Sustainability, 2014). To date, the Grid consists of 8 archetypes or sustainable strategies and 52 related *mechanisms for sustainable business model innovation*. It aims to inspire businesses to reconceive the way they operate and become more future proof. For a review of the Grid see page 48.

The Morphology will draw both on the eight sustainable strategies and on the mechanisms. The strategies are:

- Optimization
- Circularity
- Substitution with Renewables
- Functionality
- Stewardship
- Slow Consumption
- Co-Creation
- Social Entrepreneurship

Due to the large number of to-date-identified mechanisms, only a few mechanisms can be displayed in the morphology. The selection includes: Increased Functionality,

[35] Link: http://hdr.undp.org/en/composite/Dashboard2#d

Lean Manufacturing, Circular Economy: Zero Waste, Product Service Systems, Ethical Trade, Slow Fashion, Open Innovation and Bottom of the Pyramid. The remaining mechanisms are represented under 'Others.' For a full overview of the mechanisms see http://www.vlaanderen-circulair.be/bmix/.

SUSTAINABLE DEVELOPMENT GOALS (SDG)

Companies can use the Sustainable Development Goals (SDGs) as a compass for strategic decision-making to better align their business models with their evolving sense of societal purpose creation. The Insect Economy can contribute to reaching at least 10 SDGs. By which means it can contribute as described in the following subsections.

SDG 1: END POVERTY

836 million people still live in extreme poverty and the overwhelming majority of people living on less than 1,25 US dollars a day belong to two regions: Southern Asia and sub-Saharan Africa. Thus, SDG 1 aims to solve the causes of poverty. Insects as food can help solve this problem. In fact, insect farming for human food on a commercial scale originated in Southeast Asia in the late 1990s. There, it still provides important livelihood opportunities for mostly rural people. In warmer hemispheres, insect farms require little sophistication and are therefore inexpensive.

In some developing countries such as Thailand, Vietnam, and Laos, where insect rearing is widespread (Yhoung-Aree and Viwatpanich, 2005), insect-rearing systems have not been mechanically optimized and depend greatly on manual labor. This makes it particularly interesting to create local job opportunities. In Thailand for example, 140 000 Thai households reared silkworms in 2004. This amount represented 80 percent of the country's total silkworm production, generated about 46.5 million Euros (US$50.8 million) and accounts for an important source of income (Van Huis et al., 2013). Therefore, insect farming is seen as an opportunity to create employment and get people out of poverty especially in Bottom of the Pyramid nations and emerging markets. Because insect farming can be done by men, women, and children equally, it can contribute to raising the proportion of women in paid employment and the economic empowerment of women (SDG 5). Even in Western countries where there is a tendency to automatize production (e.g., HiProMine, Aspire, Nordic Insect Economy), other types of employment will be generated along the emerging value chains – be it during insect processing or retail.

SDG 2: ZERO HUNGER

The United Nations Food and Agriculture Organization (FAO) estimates that about two billion people are affected by malnutrition. Among the most prevalent causes of malnutrition are lack of calories and proteins, which often leads to stunted growth, higher susceptibility to disease, and death. In addition, the chronic deficiency of essential vitamins and minerals lead to malnutrition and is better known as hidden hunger. Hidden hunger is less overtly visible, but can have dramatic negative and often lifelong consequences for health, productivity, and mental development (Muthayya et al., 2013).

In addition to the current status quo of malnutrition, the world is experiencing population growth to approximately 9 billion people by 2050 as well as an increasing trend for more meat consumption among the middle class, especially in emerging markets. Both trends increase the challenge of food scarcity and malnutrition. Without this demand for meat, however, the current food production would be sufficient to feed a vegetarian world population (OECD, 2013). The FAO estimates that between 2010 and 2050 meat production will rise by nearly 70 percent, aquaculture by 90 percent and dairy by 55 percent. In turn, these animals require shelter, space, and feed. Thus alternative meat and feed sources are needed. Those have to be nutritionally adequate, safe and healthy to satisfy food demand, guarantee security and assure a healthy life for present and future generations.

Insects constitute of important nutrients for a healthy life both for humans and livestock animals (see again section 10.09, NUTRITIONAL VALUES). Not only are they rich in protein content, but they also contain high amounts of essential vitamins and minerals (calcium, copper, magnesium, manganese, and zinc). In fact, Latunde-Dada et al. (2016) have shown that insects may provide more of these micronutrients than a sirloin beef.

Some ventures recognized the opportunity highlighted by SDG 2. Protein Synergy (Switzerland), for example, formulated the goal that “We want to contribute to sustainable agriculture, global food security and decrease malnutrition in developing countries.” Kreca (now Proti-Farm) states: “Due to the increase in the world population (2013; 7 billion - 2045: 9 billion) the demand for protein cannot be fulfilled by conventional sources like different types of meat and our insects are the answer to this. We do this in a healthy environmental way and plan to establish various breeding plans in different countries worldwide to meet the ongoing demands.” Furthermore, Hargol FoodTech which focuses on grasshoppers as human food is driven by the challenges of malnutrition. Its webpage states that “Chockfull of whole protein, vitamins, and healthful fatty acids, with no cholesterol or saturated fat, grasshoppers could be one answer to the chronic malnutrition affecting approximately 805 million people, according to the United Nations.”

SDG 3: GOOD HEALTH AND WELL-BEING

In section 10.89.19, the benefits of insects as therapeutic, wellness and superfood were described (see p. 90). It showed that some insects are commonly used for medicinal purposes such as the ant, *Oecophylla smaragdina* (which in some places is used close wounds) or the maggot therapy, which is a cost-effective and efficient form to close wounds. More than that, insects have also been identified as a source of medicinal substances in general (Piper, 2017). Research in this field, however, is only in its infancy.

SDG 7: AFFORDABLE CLEAN ENERGY

Some researchers have addressed the potential of insect oil in its value as a biofuel (see page 86). While this might be technically possible, no economically viable solution has been marketed yet. Still, especially if insects as resources cannot be used as food or feed, this application might become more attractive.

SDG 9: INDUSTRY, INNOVATION, AND INFRASTRUCTURE

"Inclusive and sustainable industrial development is the primary source of income generation, allows for rapid and sustained increases in living standards for all people, and provides the technological solutions to environmentally sound industrialization" (United Nations, 2016b; (SDG 9)). The understanding of inclusive and sustainable industrial development has different meanings in the Insect Economy depending on where the development takes place.

One promising insect-based solution consists of rearing insects as food and feed. Its environmental benefits are that insect rearing is an integrated (circular) system where ideally organic residues are used as insect feed, and near-to-no-waste is produced.

Some technologies to implement this solution are low tech. Other technologies adopt a high degree of automation through specific software-based solutions - which reduces the need for manual labor to a minimum. One specific solution approach consists of controlled atmosphere shipping containers of various sizes that can be manually operated to farm insects. The system is robust and at the same time, sufficiently flexible in terms of layout and interior climate so that it can be modified to fit different insect species.

Thus, there exist multiple technologies of insect rearing facilities, which can be adapted to the needs of different social groups. There exist high-tech solutions that are suitable for industrialized countries suffering from high labor costs and there exist low-tech solutions that enable the access of low-income producers to rear their own insects. Furthermore, as the example of the shipping containers shows, rearing facilities can be implemented locally – thereby increasing the resilience of local communities to produce their own food – and they can be modular, which allows for a scale-up solution.

SDG 11: SUSTAINABLE CITIES AND COMMUNITIES

The sustainable development goal on sustainable cities and communities aims to support cities to thrive and grow, while improving resource use and reducing pollution and poverty. It further aims to generate opportunities for all, with access to basic services, energy, housing, and transportation. In that way it addresses numerous issues such as "exerting pressure on freshwater supplies, sewage, the living environment, and public health" (United Nations, 2016b). Insects can indeed present a solution to a number of these challenges, as the sustainable city concepts of the Belatchew project and Third Millennium Farming (3MF) concept propose. Both use insects as organic waste converters and as sources of food and feed. Furthermore, they integrated the ecosystem services of pollination in their sustainable city concepts (see page 91).

SDG 12: RESPONSIBLE CONSUMPTION AND PRODUCTION

"Sustainable consumption and production are about promoting resource and energy efficiency, sustainable infrastructure, and providing access to basic services, green and decent jobs and a better quality of life for all. Its implementation helps achieve overall development plans, reduce future economic, environmental and social costs, strengthen economic competitiveness and reduce poverty" (United Nations, 2016).

Insects as organic waste converters can address multiple goals of this SDG which comprises:

1. Achieve the sustainable management and efficient use of natural resources
2. Achieve environmentally sound management of organic wastes throughout their lifecycle and significantly reduce their release to air, water and soil to minimize their adverse impacts on human health and the environment
3. By 2030, substantially reduce waste generation through recycling

Insects can be reared at different scales: from household scale, all the way to industrial scale. In that way, they can be used to convert organic waste materials efficiently. Those materials may stem from different sources: farm waste, pre-consumer waste, and household waste. Thus, if insect farms are located close to industries and other sources that produce organic waste, then this waste can be sustainably managed and efficiently used. In turn, the negative impact produced by waste could be diverted and subsequently, its harm to the air, water and soil would be minimized as well as the harm to human health. Thus, insect farms can be an approach for sustainable waste management practices.

Some entrepreneurs have recognized this recycling opportunity, which leads to close-to-zero-waste-production. A pioneering company in the insects-as-feed-space, AgriProtein, coined these business opportunities, the "waste-to-nutrient recycling industry" (Brown, 2017). Another company, Entocycle, refers to this potential as "recreating nature's processes and feeding wasted food to insects in a bio-refinery in London." The company Bioflytech has developed technology able to create value added from a diverse set of organic waste: agricultural sub-products, residues from farming, hotel, and alimentary sectors, and certain types of specific waste associated with contaminating the environment, such as meat flours, tanned skins, sewage sludge" (Bioflytech, 2013).

Ycera (China) uses food waste vegetables, fresh tree leaves, wheat brans and special formula ration as feedstock for superworms (*Zophobas morio*). In the next step, the larvae are used as animal feedstock, and the fresh pupae are sold to restaurants. Furthermore, the company proposes to further process the pupae for health and medical purposes.

Responsible production and consumption are at the heart of the current problems that lead to global challenges. This fundamental problem can be addressed in the Insect Economy where entrepreneurs demonstrate sound knowledge and concern for these problems in their company mission and vision statements. So does Entologics (Brazil) stating that "Our goal is to propose a respectful and dynamic interaction between nature and humans, without neglecting sound economic growth and the management of a profitable business." Additionally, Entomo Farms (Canada) which declares "Our obligation is to sustain [the environment], conserve it, perpetuate it — to keep the Earth by doing our best to protect all life systems and life forms. […] It is through this awareness, and passionate conversation with one another, that brought the genesis of Entomo Farms - producing insect protein as a viable, and altruistic response to the global crisis; (food, water, natural resources) that will imminently be upon us."

Furthermore, the statement of Ycera (China) also makes clear how multiple value propositions can be generated by using this approach and how valuable insects as bioresources may become. Especially, biotechnology opens up immense opportunities to develop new materials. The following projects (which were already addressed earlier, see page 99) give an idea of this potential:

- ChitoTex which studies insect-based chitin as a bioresource for the textile industry,
- CHITINSECT which explores the extraction and derivatization of chitin from insects, and its applications in agriculture and chemistry or
- TeFuProt which analyses the potential of techno-functional proteins.

SDG 13: CLIMATE ACTION

Using insects as food or feed is far more climate-friendly[36] compared to chicken, pork, or beef. According to the IPCC (2014), the current food production system is a leading cause of climate change and water scarcity. The livestock industry alone now accounts for about 20 percent of the total terrestrial animal biomass. As such, it is responsible for 18 percent of the CO_2 greenhouse gas emissions worldwide, emits 37 percent of anthropogenic methane and 64 percent of anthropogenic ammonia emissions, which contribute significantly to the depletion of oxygen in water bodies and acidification of soils (FAO, 2006).

According to Oonincx et al. (2010) per kilogram of meat product, insects emit much lower quantities of greenhouse gases, such as methane (CH_4) and nitrous oxide (N_20), than conventional production animals, such as cattle and pigs. For the example of the mealworm, *Tenebrio molitor*, it can be noted that the production of one kilogram requires 16 m^2 on which the mealworms emit 14 kg of CO_2. In contrast, to obtain one kilogram of pork 3.0 times more space (48 m^2) is required and 2.7 times more CO_2-emissions are produced. However, Halloran et al. (2016; p. 57) note that accurate measurements of the emissions are lacking and "that CO_2 production is highly dependent on species, metamorphic stage, temperature, feeding status, and level of activity."

Additionally, regarding water savings insects represent an attractive alternative if used as a substitute for conventional livestock production. Specific measurements in this respect still need to be carried out. However, Van Huis (2013a) estimates that one kilogram of insect-based meat only requires 8.4 liters of water while one kilogram of chicken meat requires approximately 4.300 liters of water, pork requires 6.000 liters for one kilogram, and cattle requires 15.400 liters (4 times more) of water to produce one kilogram of beef. Those 8.4 liters, however, are mostly already contained in feed especially when sourced from organic waste streams. The yellow mealworm and the lesser mealworm, for instance, can be reared on organic side streams. At the same time, they are also drought resistant (Van Huis, 2013b; p. 566).

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[36] Several insect species such as cockroaches (Blattaria), termites (Isoptera), and scarab beetles (Scarabaeidae) are known to produce significant amounts of methane. (Halloran, 2016)

Ventures in the food and feed sectors use these environmental benefits in their communication strategy. Big Cricket Farm (US) states that “it only takes about a gallon of water to raise one pound of crickets, compared to 2,000 gallons of water for a pound of cow. Moreover, crickets produce 100 times fewer greenhouse gases than cows.” Bugsolutely (Italy/Thailand) further argues that “The percentages of greenhouse gas emissions from insect farming are hugely less than livestock farming which is the largest contributor to global greenhouse emissions at 18 percent.”

SDG 14: LIFE BELOW WATER AND SDG 15: LIFE ON LAND

The SDG 14 – life below water – comprises to efficiently regulate harvesting and end overfishing to restore fish stocks while SDG 15 primarily addresses the issues of deforestation. The root causes of both SDGs are linked to the livestock industry because the animals are fed with fish oil, fishmeal, and soya. While large soya fields replace native land and lead to deforestation and biodiversity loss, the use of fish in animal feed contributes to overfishing. 30 percent of wild caught fish is used to satisfy the demand of the livestock industry. Fundamental fish species (Peruvian anchoveta, blue whiting, capelin and Atlantic herring and Chilean jack mackerel) used for fishmeal production are almost entirely exploited or fully exploited leaving no margin for further expansion. This leads to direct and indirect adverse effects such as sedimentation of coastal areas and increased vulnerability of ecosystems in general. Insects are identified as substitutes for fishmeal and fish oil (and soybeans) (FAO, 2006).

Especially ventures that offer insects as feed actively communicate the benefits of using insects to alleviate this challenge. Kulisha (US/ Kenia) for instances communicate the alarming message that “Aquaculture is booming worldwide and is increasingly being seen as a good way to produce protein for a growing population. But there’s a problem — fish feed for aquaculture farms is made from wild-caught fish like anchovies and sardines. These fish are caught using highly destructive fishing methods — like trawling — that result in unintentional by-catch and the destruction of coral reefs. Also, more than 90 percent of the world’s fisheries are either fully-exploited, over-exploited or collapsed. We are feeding fish to fish, and it doesn’t make sense.” In addition, Entologics Nutrientes Sustentáves (Brazil) communicates on its website that “33 percent of fish produced in the world today are already used in feed for farmed fish and livestock, not humans” and that “More than 75 percent of the world's wild fish populations are already fully exploited or even exhausted. Increased fishing will destroy our oceans and, if fishing diminishes, fishmeal prices will increase.”

CONCLUSION

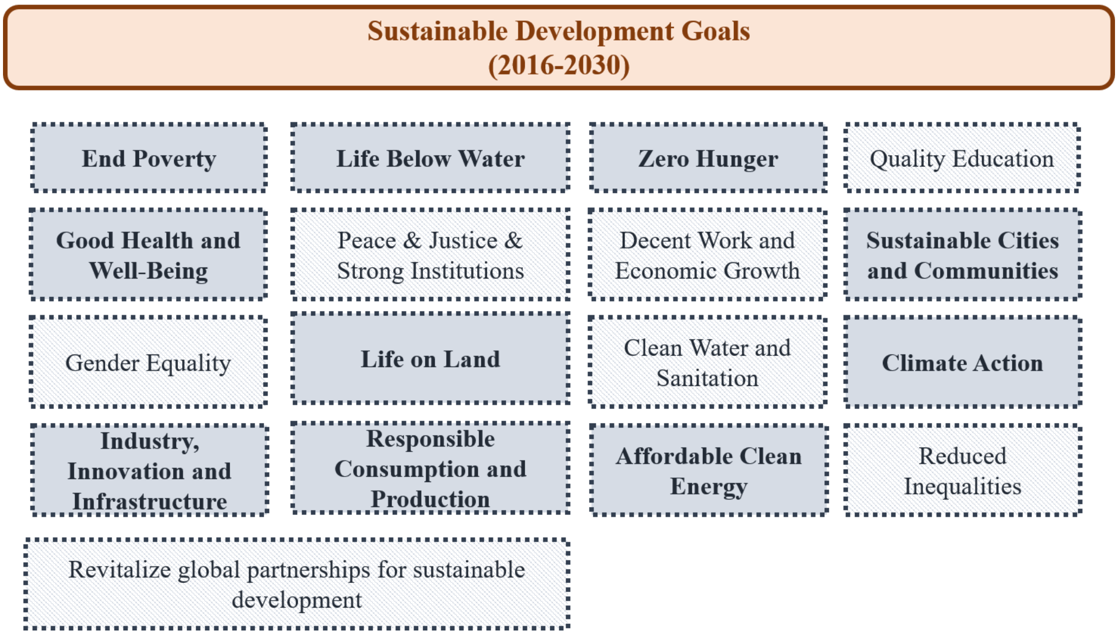

Figure 28: Link between the SDGs and the Insect Economy
(Relevant SDGs are highlighted in bold and dark blue background)

The Insect Economy holds solutions approaches to address at least 10 out of 17 Sustainable Development Goals directly (see Figure 28) and potentially more if collateral effects are taken into account. It proposes key solutions to the systemic problems in the food and agriculture sector which requires rethinking of the way we grow, share and consume our food. Indeed, the Insect Economy has the potential to provide nutritious food for all and generate decent incomes, while supporting the people-centered rural development and protecting the environment.

GLOBAL CHALLENGES

Business Opportunities related to insects can be uncovered by focusing on current global challenges. This focus is the opposite perspective of that of the Sustainable Development Goals and was initially discussed in 2.1. Instead of repeating the explanations, Figure 29 provides an overview of the Global Challenges to which the Insect Economy can contribute solutions.

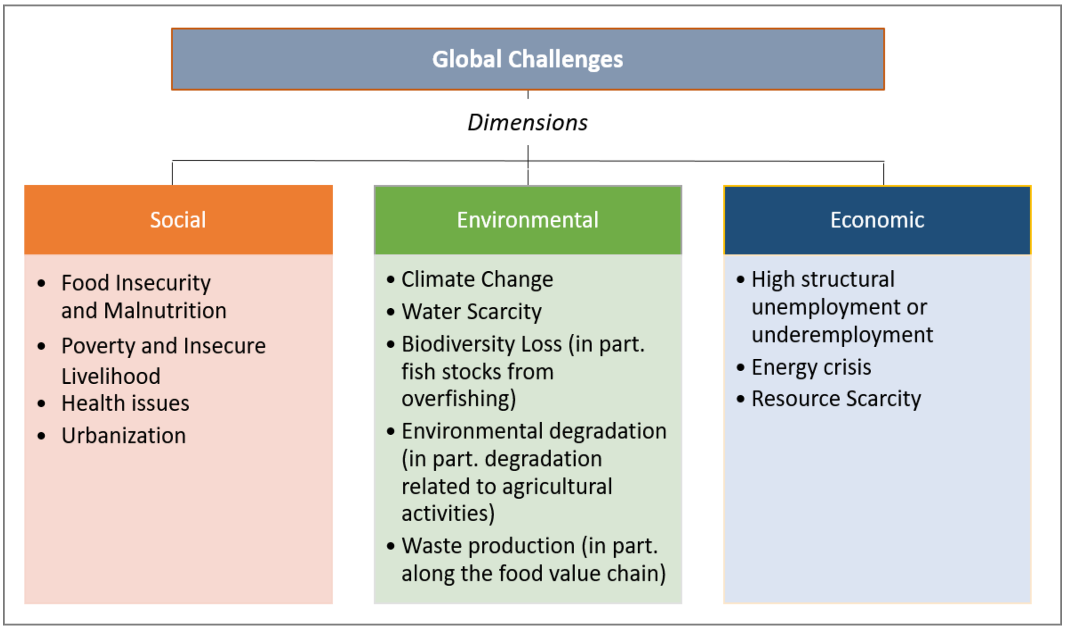

Figure 29: Global Challenges and the Insect Economy

The reason why Global Challenges are listed in addition to the Sustainable Development Goals is that companies, especially in the area of insects as food and livestock feed and pet food, recurrently refer to how their products contribute to solving global challenges. Numerous examples are provided in the description in the heading before (see again pp. 119).

PLANETARY BOUNDARIES

Business Opportunities can also be identified by using the planetary-boundaries-concept (see page 13 or Figure 3). It serves as a tool to reveal the true cost of production (and consumption) and thereby, helps uncover information asymmetries.

By converting insects in a major source of food and feed, certainly more planetary boundaries could be addressed than the nitrogen cycle (*biogeochemical flows*). It would also contribute to:

- Adapting to climate change and reducing freshwater use (for both see SDG 13),
- Halting land-system change (see SDG 14) and biodiversity loss (biosphere integrity) (for both see SDG 14),

- Reducing chemical pollution: Charlton et al. (2015) conducted research feeding the house fly (Musca domestica), blue bottle fly (*Calliphora vomitoria*), blow fly (Chrysomya spp) and black soldier fly (Hermetia illucens) with waste contaminated with over 1000 types of contaminants including persistent pollutants, such as heavy metals, pesticides, veterinary medicine, dioxin and mycotoxins. Those contaminants are routinely monitored to ensure the safety in the animal feed sector. From the research result the researchers (2015; p. 7) concluded that "The larvae analyzed generally possessed levels of chemical contaminants below recommended maximum concentrations suggested by bodies such as the European Commission, the World Health Organization and Codex." Thus, there is great potential that insects can be used to transform organic matter and thereby, reduce environmental contamination. (Cickova et al., 2012, Gobby et al., 2013, Diener et al., 2015, Lalander et al., 2015, Zhu et al., 2015)

As with the Global Challenges, the reason why Planetary Boundaries are listed in addition to the Sustainable Development Goals is that companies, especially in the area of insects as food and livestock feed and pet food, refer to how their products contribute to reduce the pressure on the planetary boundaries. Some examples were provided in this subsection.

SUSTAINABILITY FROM THE BUSINESS CASE PERSPECTIVE

The concept of a sustainable business case was first discussed in this thesis on page 40. From the description of the CPAs (acronym for Products by Economic Activity) emerged that insect-based solutions are not only viable business solutions, but that they can also deliver *natural cases* and *social cases.* If solutions produce a business case together with a natural and a social case, then these solutions are *triple bottom line* solutions. I will allude to some examples that create a *natural* and a *social case* in addition to a business case and to examples that create triple bottom line solutions. Solutions that only produce one or another (i.e., only social cases, only natural cases, only social-natural case) are excluded because the focus lies on creating business opportunities and the precondition for creating business opportunities is a business case (Dyllick and Hockerts, 2002).

THE NATURAL CASE - BUSINESS CASE

Beekeeping is an activity that relies on a functioning ecosystem. Without the availability of flowers, beekeepers could not assure survival of the business or obtaining their products and services which is why – at least for the majority of beekeepers – caring for the environment is an intrinsic part of caring for the bees (Imhoof, 2012). Thus, for beekeeping, the natural case is inseparably linked to the business case.

Moreover, entomoremediation which refers to using insects for organic waste conversion to produce compost generates a natural and a business case. The recycling of the waste ideally is eco-effective because it increases resource productivity by providing absolute improvements regarding waste conversion, close-to-zero-waste-production, to generate natural compost (see page 95).

THE SOCIAL CASE - BUSINESS CASE

A social case is given if insects as biological resources can help alleviate social burdens. Such an effect is produced by the maggot therapy which was earlier presented as a cost-effective way to cure open wounds (see again SDG 3). Another example that can produce a social case is when insects become a source of food and income. To date, the majority of edible insects are collected in the wild (Rumpold and Schlüter, 2013).

The collection of insects in the wild produces a social case only under contingent conditions. These conditions include that there are safe and cost-effective farming systems or sustainable management plans in place, which guarantee that the collected insects are not contaminated with herbicides and pesticides. To enable a long-term viability of this approach, it is vital to avoid over-collection of insects because this can disturb natural balances. In Thailand, for example, “available insects have decreased in both quantity and the number of species, due to increased demand and decreased insect habitats” and are mostly imported from Cambodia where there are still ample natural habitats for insects (Siriamornpun and Thammapat, 2008).

THE TRIPLE BOTTOM LINE

Triple bottom line solutions are created when a business solution produces a social and a natural case in addition to a business case. Such a solution is, for instance, produced when people combine using insects as natural pests and at the same time, as a source of food or feed. This approach is recognized as *semi-cultivation* and can be found in entomophagous countries. In parts of South East Asia, the tree-dwelling ant, *Oecophylla smaragdina*, (an insect that is also used as a traditional means to close wounds) has been used as an effective biological control agent against agricultural pests. The grubs of the ants (larvae and pupae) are also collected and sold in local markets as a delicacy. This duty is often done by women who sustain their livelihood with this work. A similar approach is practiced with the palm weevil, *Rhynchophorus ferrugineus* (Van Itterbeeck, 2014).

Another triple bottom line approach consists of collecting pest insects such as grasshoppers from agricultural fields and using them as a source of food and feed. Even though it is currently not an economically viable solution worldwide, at least in Bottom of the Pyramid economies with intensive agribusiness activities, it holds the potential to produce multiple social, environmental and economic benefits (Cerritos Flores and Klewer, 2015). It could address (1) the large-spread problem of malnutrition by eating nutrient-rich insects and, (2) avoid contamination and health concerns originating from pesticides on agricultural fields, and (3) it could become a source of income especially for local communities. Feasibility of this approach has been shown by the Philippines and Japan, where it was the starting point of organic rice farming (Mitsuhashi, 2005, Mituda–Sabado, 2014).

CONCLUSION

The examples show that a subset of economic activities in the Insect Economy attains environmental savings or burden relief effects that outweigh the “investment” of resources, incurred by the innovation's introduction (cf. Paech, 2007). It provides solutions for managing resources in a way that it reduces land footprints over the production, distribution and consumption cycles and holds opportunities for responsible and inclusive management solutions.

DRIVERS FOR SUSTAINABILITY

Business drivers were defined in section 2.4.4 as variables that directly or indirectly influence economic success (Schaltegger et al., 2012). Core business drivers for sustainability are, e.g.,

- The potential to grow by enabling better access to certain markets and access to new markets,
- First-mover advantages that foster innovation,
- Increase reputation and legitimacy,
- Risk reduction, and long-term orientation,
- Lower cost of capital and labor costs.

DIFFUSION DYNAMICS

Identifying underlying diffusion dynamics is fundamental to make an appraisal whether or not a business opportunity will be successful on the market or not. In their conceptual framework about the diffusion of sustainable innovation, Fichter and Clausen (2016; p. 37) identified seven critical influencing factors for market acceptance of sustainable innovation, namely:

(1) Market power of established providers,
(2) Governmental push and pull,
(3) Influence of pioneers,
(4) Purchase incentives,
(5) Compatibility with routines,
(6) Prices and economic viability,
(7) Transparency of innovation.

These elements are integrated as features in the morphology.

RISK FACTORS

Due to the great diversity of the Insect Economy, it is challenging to address its risk factors. For that reason, this subsection concentrates on the scope 'insects as' food, livestock feed, pet food, and organic waste converters, which at the same time, is the scope of research of chapter 4. The following risk factors are addressed in further detail: potential risks exist concerning the mass production of insects throughout the value chain, potential risks for human health, animal welfare and ethical aspects and the risk of business as usual instead of a transition towards sustainable development. For a review about risk factors see 2.5.3.

RISKS RELATED TO VALUE CHAIN

Despite the sustainability potential that insects hold, the real sustainable outcome depends on multiple factors. Those include the context in which insect farms are put in place and their production processes. The degree of sustainability of in the value chain can be identified through environmental impact assessment methods such as a life cycle assessment (LCA). An LCA systematically analyses the environmental impact of products during the whole life cycle and are based on clear standards such as ISO 14040:2006. Such standards adapted for insect rearing do not yet exist, but they would ideally consider the construction of the production facilities, feed intake, production process, transport, processing, and storage. (Halloran et al., 2016)

Because insect rearing practices are – at least in industrialized countries – in their infancy, only six case studies were conducted (Halloran et al., 2016). Regardless of their limited number and comparability, they make clear that to produce sustainable outcomes it is important to consider the species and its required rearing conditions, its ability to recycle organic waste and the economic viability to become an attractive substitute for existing - more environmentally harmful - alternatives.

RISKS RELATED TO HEALTH CONCERNS

Another not to be trivialized aspect is the one that insects are also major vectors for diseases. Despite the fact that they are poikilothermic and therefore, the risk of transmitting diseases to warm-blooded animals and humans is low, there are a number of diseases spread by insects that are well-known and cause a significant economic impact. For instance, the presence of the Tsetse fly in some regions in Africa makes it impossible to rear bovine. Therefore, the potential health risks require sound studying to avoid such problems.

Furthermore, Verkerk et al. (2007) anticipate that some of the problems of breeding cattle may also occur at the insect farms, such as increased vulnerability to diseases. There is a tendency among insect breeders that patterns from livestock breeding are repeated (see page 94).

Moreover, insects can be a source of inhalant allergens (e.g., cast skins, excreta) and produce defensive secretions, which might be irritating for people working with them. Such health risks require in-depth research to be anticipated and thereby avoided.

ANIMAL WELFARE AND ETHICAL ASPECTS

Animal welfare issues and ethical aspects are also relevant to insect rearing facilities (Potthast, 2016). Insects in daily life are often seen as pests and contaminants. However, as soon they are farmed for food and feed, animal welfare rules about husbandry and killing will come into play. Sound research findings on welfare issues are still lacking. To ensure that insects are farmed with no pain, injury, and disease, but also without discomfort, it needs to be defined to what extent the subjective concepts of pain and discomfort apply to insects.

A common approach to avoid any animal welfare issue is putting insects in a dormant state called diapause. They are then placed in a deeper freeze killing them humanely.

This, however, represents a cost factor to the producers. Their willingness to adopt animal welfare aspects will thus depend on the economic viability as well as on the values and principles of the ventures (cf. Verkerk et al., 2007, Van Huis et al., 2013).

RISKS OF BUSINESS AS USUAL INSTEAD OF A TRANSITION TOWARDS RESILIENT FOOD SYSTEMS

The introduction of insects as food and feed should be understood as a process within a major transition towards resilient food production and consumption systems instead of being "meat business as usual" (Potthast, 2016). Van Huis (2016) commented at the Symposium about Insects as Food and Feed in Berlin in 2016[37] that the risk of repeating business as usual practices might, in fact, become a reality in the insects as food and feed business as well. There he rose attention to the development of production practices that might also include genetically improving insect species (breeding), the use of different strains and inbreeding and outbreeding – even though these developments are in "a very preliminary phase or have not even started yet." Those developments correspond to the ones already seen in the meat industry, which have led to devastating consequences for animal welfare (Chemnitz and Benning, 2013).

This technological interference may threaten social justice because small-scale farmers may not gain access to these technologies. Recalling that insect farming was mainly addressed as a solution to affront food security and poverty, this risk requires close consideration (cf. Sheppard et al., 2011, Delvenne and Hendrickx, 2013).

The question is whether the private sector prioritizes on food safety and technical innovation over food security, conservation, and traditional livelihoods. The emerging doubt is if the evolving solutions from the current pioneers - which will probably set global standards - will actively strive for social and environmental benefit creation. Since making an insect farming system efficient "only" requires technological advances, however, to be effective, just and equitable particularly in rural economies, requires local capacity building and work within the limits of regional conditions. Answering this question will be part of chapter 4.

3.6.4 RESULT: MORPHOLOGY OF THE INSECT ECONOMY

The morphology comprises 22 dimensions and 130 features. Thereof, four dimensions and 23 features refer to the overall category *insects*, nine dimensions and 46 features to the overall category *economy*, and nine dimensions and 61 features to the overall category *sustainability.*

These dimensions and features are the building blocks of the typology of sustainable business opportunities that is subject of the following research chapter. In the process of developing the typology, the morphology will be subject to modifications to fine-tune it to the reality of the Insect Economy. The modifications and the final morphology are described in 4.4. Table 7 displays the full morphology.

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[37] Symposium „ Insekten als Lebens- und Futtermittel " Bundesamt für Risikobewertung (BfR), Berlin, 24. Mai 2016.

Table 7: Morphology of the Insect Economy

	Dimensions	Features								
Insects	**Insect Orders**	Beetles (Coleoptera)	Moths, Butterflies (Lepidoptera)	Fly (Diptera)	Ants, Wasps, Bees (Hymenoptera)	True Bugs (Hemiptera)	Grasshopper, Cricket (Orthoptera)	Others		
	Ecosystem Services	Supporting Services	Provisioning Services	Regulating Services	Cultural Services					
	Rearing Practices	Controlled Environment	Semi-Cultivation	Captured in the Wild						
	Applied Research about Insects	Forensic Entomology	Economic Entomology	Medical Entomology	Applied Entomology	Yellow Biotechnology	Industrial Entomology	General Fields of Research that include Insects	Fields of Specialization	Others
Economy	**Products of Economic Activity**	Products of Agriculture, Hunting & Related Services	Manufactured Products	Water Supply; Sewage, Waste Mgm. & Remediation Services	Wholesale & Retail Trade Services	Professional, Scientific and Technical Services	Arts Entertainment und Recreation Services	Service of Households and Services produced by households own	Others	
	Insects as	Food	Livestock Feed and Pet Food	Provider of diverse bio-based Materials	Organic Waste Converter	Natural Enemies and Pollinators	Others			
	Business Model Building Blocks	Key Partnerships	Key Activities	Key Resources	Cost Structure	Value Proposition	Customer Relationship	Cannels	Customer Segment	Revenue Streams
	Innovation Object	Product	Processes and Technology	Business Models						
	Type of Customer	Producer (B2B)	Final Consumer (B2C)							
	Geographic Origin of the Business	Africa	Asia	Oceania	Europe	Middle East	North America	Latin America		
	Geographic scope	Local	Regional	National	International					
	Markets according to degree of Human Development (HDI)	Low Human Development (Bottom of the Pyramid Markets)	Medium Human Development	(Very) High Human Development (Consumerist Economies)						
	Life Cycle of the Industry	Embryonic Stage	Introduction Stage	Growth Stage	Maturity Stage	Decline Stage				
Sustainability	**Business Model Grid: *Sustainable Strategies***	Optimization	Circularity	Substitution with Renewables	Functionality	Stewardship	Slow Consumption	Co-Creation	Social Entrepreneurship	
	Business Model Grid: *Mechanisms for Sustain. Business Model Innovation*	Increased Functionality	Lean Manufacturing	Circular Economy: Zero Waste	Product Service Systems	Ethical Trade	Slow Fashion	Open Innovation	Bottom of the Pyramid	Others
	Planetary Boundaries	None	Loss of Biosphere Integrity	Climate Change	Freshwater use	Land system change	Stratospheric Ozone Depletion	Altered biogeochemical cycles	Atmospheric aerosol loading	Ocean Acidification
	Sustainable Devel. Goals (2016 – 2030)	Not considered	Zero Hunger	Climate Action	Life below Water and Life on Land	Responsib. Production & Consumption	Clean Water and Sanitation	Good Health & Well-being	Others	
	Global Challenges	Malnutrition & Food Scarcity	Biodiversity Loss	Environmental Degradation	Waste Production	Resource Scarcity	Health Issues	Others		
	Sustainability from the Business Case Perspective	Business Case - Natural Case	Business Case - Social Case	Triple Bottom Line						
	Sustainable Busin. Drivers	Expand Potential to Growl	First-Mover Advantage	Increase Reputation and Legitimacy	Risk Reduction	Reduction of Cost of Capital and Cost of Labor	Others			
	Diffusion Dynamics	Compatibility with Routines and Culture	Governmental Push and Pull	Prices and Economic Viability	Market Power of established Providers	Influence of Pioneers	Purchase Incentives	Transparency of Innovation		

	Risk Factors related to	The Value Chain	Human Health	Animal Welfare and Ethical Aspects	Business-As-Usual Production Processes

3.7 CONCLUSION

This chapter aimed to explore, describe and characterize business opportunities around insects as biological resources (research question 1). To do so, the focus was set on the meso- or industry level. Three major insights were gained. These are:

- First, the literature review justified the high relevance that insects have for nature and society (see 3.3), and in the context of science (see 3.4).
- Second, a vast number of industries could be identified in which insects as biological resources were used in the past, are currently used or will be used in the future (see 3.5). This extensive portfolio of industries justified the introduction of the term '*Insect Economy.*' This term was defined as "a subset of innovative and sustainable products, processes, and services resulting from the Bio-Economy, which bases on the use of insects as biological resources" (see 3.1) (Sustainable Innovation).
- Third, the '*Insect Economy*' was characterized by employing the morphology. It consists of three overall categories: insects, economy and sustainability (see 3.6). The morphology comprises 21 dimensions and 127 features. Thereof, four dimensions and 23 features refer to the overall category *insects*, nine dimensions and 46 features to the overall category *economy*, and ten dimensions and 58 features to the overall category *sustainability.* The morphology is empirically tested in section chapter 4 (see section 4.4).

The development of the Insect Economy concept, the identification of the business opportunities based on insects, and the morphology, build the fundament for the assessment and classification of sustainable business opportunities (research question 2). Research question 2 will be addressed in the upcoming chapter.

CHAPTER 4: TYPOLOGY OF SUSTAINABLE BUSINESS OPPORTUNITIES IN THE INSECT ECONOMY

4.1 INTRODUCTION

Building on the Morphology of the Insect Economy, this research chapter answers the following question: *How can sustainable business opportunities related to insects be assessed and classified?* In the context of entrepreneurship, the most logical approach to obtain information about business opportunities is by interviewing entrepreneurs active in the field. In that way, it can be assessed in what ways the opportunities are currently recognized and exploited. For that reason, I build on interviews for the data collection. Moreover, for the classification of the information, I draw on a typology as a tool to identify and characterize ideal types by representing a unique combination of the attributes that are believed to determine the relevant outcome.

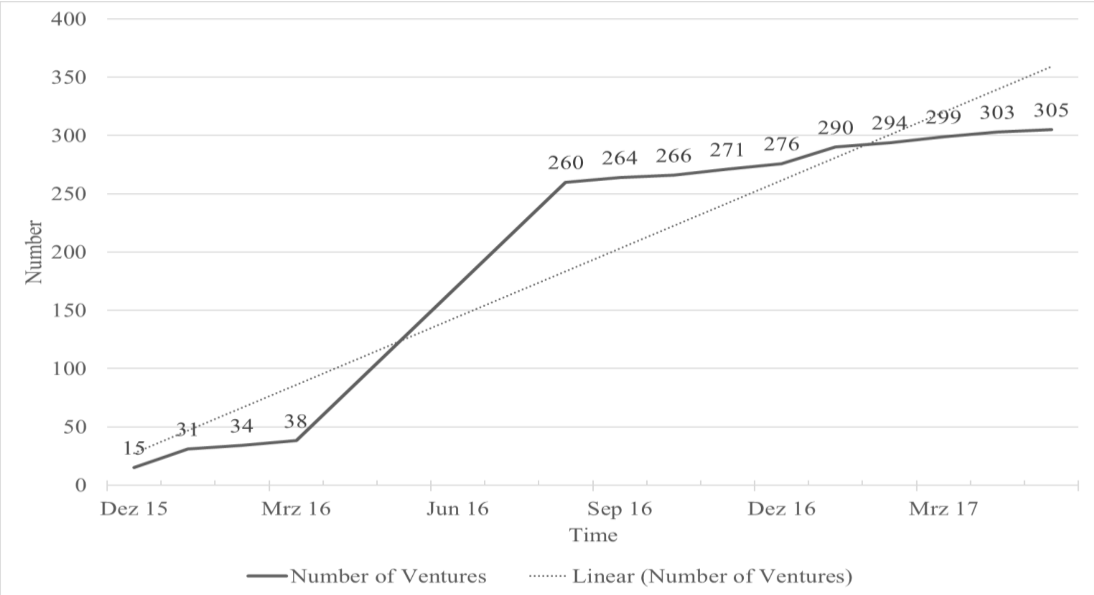

Figure 30: Emergence of Ventures around Insects as Food, Feed, Petfood and Organic Waste Converters
Source: Chart based on Taponen (2017)

For the analysis, I limited the scope to 'insects as' food, feed, pet food, and organic waste converters. I did so because the Insect Economy is very complex and diverse as the morphology has shown. For the selection of these industries, I applied two criteria: First, these value propositions demonstrated vast innovation potential during the exploration of business opportunities in Chapter 3, and second, they are very dynamically developing as Figure 30 shows.

In this chapter, I first explain how I proceeded with the data collection and synthesis. Then, I elaborate on the process to develop the typology, and at the end, I draw conclusions from the results.

4.2 RESEARCH METHOD

The research method to develop the typology of sustainable business opportunities builds on the morphology of the Insect Economy. It is useful to study the ventures within the Insect Economy and derive a systematic theory about them (see 1.4.2). In this section, I describe how I proceeded with the data collection and the data analysis.

4.2.1 DATA COLLECTION

The data collection consisted of qualitative research using semi-structured interviews with open questions (Bogner et al., 2014). Using interviews is a straightforward approach to obtain facts, attitudes and experiences (Silvermann, 2013). Since the field of insects as food, feed, pet food and organic waste conversion is in a nascent stage, and it is unknown in what ways it contributes to our understanding of sustainable entrepreneurship, this approach was considered suitable.

To collect the data, I used the eight dimensions for assessing business opportunities as guidance for the interview questions. Those dimensions were identified in section 2.4.5 and are listed again in Table 8. The questions that I posed to the interview partners are also based on questions developed by Fichter and Tiemann (2015) and information that I obtained during the interview preparation. For the preparation, I gathered archival data from internal and external sources, including the websites of the ventures, newsletters, press releases, and social media news dealing with the venture. An example of an interview guideline is provided in Appendix 7.

Table 8: Dimensions for Assessing Sustainable Business Opportunities

1.	Business Model Building Blocks applied to Morphology dimension 'insects as'
2.	Business Model Innovation Grid
3.	Sustainable Development Goals
4.	Global Challenges
5.	Sustainability from the Business Case Perspective
6.	Sustainable Business Drivers
7.	Diffusion dynamics.
8.	Risk factors

UNIT OF ANALYSIS AND INTERVIEW PROCESS

The unit of analysis included all ventures contained in the support database that related to insects as food, feed, pet food and organic waste conversion. In total, I identified 75 ventures in this field. It was important to reach a population that is sufficiently large to show the spectrum of business opportunities to make valid generalizations to the understanding of the business opportunities in the Insect Economy. I considered 20 interviews as a large enough population to draw meaningful results (Eisenhardt, 1989).

In total, I requested 46 entrepreneurs to participate in my research. I contacted the entrepreneurs whose ventures received intensive media coverage and those whose web communication addressed concerns for global challenges and sustainable development (see for a review SDG, page 119). As with the first case, sustainability aspects were usually mentioned by those entrepreneurs who were often exposed to the media. Thus, by focusing on this group of entrepreneurs, I assured to receive information about sustainable business opportunities.

Furthermore, I only conducted interviews with (co-)founders or with the person responsible for driving the organization. This precondition was mandatory because founders are typically the best sources for in-depth information on the underlying motives and goals that shape sustainability within a start-up. By discriminating for these criteria, I expected to receive meaningful information about the ways sustainable business opportunities are currently put into practice. This approach of data collection is known as purposive sampling (Silvermann, 2013).

24 of the requests received a positive response. Out of these 24 interviewees, 22 were proper entrepreneurs of a venture, while two interview partners were entrepreneurs as well, but of an association or a non-governmental organization (NGO). The interview responses of the association and the NGO were used as additional information for the analysis, but not for the development of the typology itself.

The interview partners were located in 14 different countries across six continental regions which is the reason most (19) interviews were conducted via Skype. In two occasions, I had the opportunity to interview the entrepreneurs directly, and in three other occasions, the founders asked for a written reply to the interview questions. For the latter three, I developed a questionnaire with open questions. The Skype and face-to-face interviews were of an average duration of 60 min and were conducted during March and June 2017.

INTERVIEW TRANSCRIPTION

All interviews were recorded (with consent) and transcribed to aid the analysis process. For the transcription I dispensed of a complete transcription since the amount of relevant information to the topic has varied widely among the interview partners (Bogner et al., 2014, p. 83). During the transcription, however, I extracted relevant information for the research question and processed it in a summarizing document.

The interviews were then validated. During the validation process, two interviews had to be excluded from the final analysis because the answers did not correspond to the questions. Furthermore, the interview responses of the association and the NGO were used as additional information for the analysis, but not for the development of the typology itself. Overall, the data collected from the 20 interviewees that directly contributed to the typology development, comprised nearly 20 hours of interview material.

To retain confidentiality of participants, the names of the organization are coded with two code elements. The first code element is assigned according to the core value proposition of the company ("insects as") namely insects as feed (Fe), food (Fo), waste conversion (W) and miscellaneous (M), if the value proposition is mixed. The second code element numbers the participants (e.g. Fe1, Fo1). These codes are used to reference the participants' quotes together with the indication of the line number (e.g. [M1_30]) to accurately present their perspectives and experiences.

Table 9 details the code, the function of the interviewee, geographic origin, core value proposition of the company ("insects as"), and forms of communication.

Table 9: Synthesis of Empirical Cases

No.	Code	Function of the Interviewee	Geographic Origin	Insects as	Form of communication
1	Fe1	Founder & CEO	Europe	Feed	Skype Call
2	Fe11	Founder	Asia	Feed	Skype Call
3	Fe2	Founder & CEO	North-America	Feed	Skype Call
4	Fe3	Founder & CEO	Africa	Feed	Written response to open questions
5	Fe4	Founder	North-America	Feed	Written response to open questions
6	Fe5	Founder & CEO	North-America	Feed	Skype Call
7	Fe6	Founder & CEO	Latin America	Feed	Skype Call
8	Fe7	Founder & CEO	Europe	Feed	Personal interview
9	Fe9	Founder & CEO	Europe	Feed	Skype Call
10	Fo1	Founder & CEO	North-America	Food	Skype Call
11	Fo2	Founder & CEO	Middle East	Food	Skype Call
12	Fo3	Founder & CEO	Europe	Food	Skype Call
13	Fo4	Founder & CEO	Europe	Food	Skype Call
14	Fo5	Founder & CEO	Europe	Food	Skype Call
15	Fo6	Founder & CEO	Europe	Food	Skype Call
16	Fo7	Founder & CEO	Europe/ Asia	Food	Skype Call

17	Fo8	Founder & CEO	Middle East	Food	Skype Call
No.	Code	Function of the Interviewee	Geographic Origin	Insects as	Form of communication
18	M1	Founder & CEO	Asia	Feed & Waste conversion as two separate core value propositions	Skype Call
19	M3	Founder & CEO	North-America	Waste converter/ Feed producer	Skype Call
20	W1	Founder & CEO	North-America	Feed/ Logistics	Skype Call

4.2.2 DATA ANALYSIS

The data analysis comprises (1) coding the transcribed interviews and synthetizing the obtained data and (2) developing the typology. The following subsection describes these steps in further detail.

CODING AND DATA SYNTHESIS

The data from the interviews was evaluated through coding and analyses with MAXQDA12, a software package for qualitative data analysis. The coding category system was developed using a combined deductive and inductive approach. The code category system bases on the dimensions for assessing business opportunities (see Table 8). In this process, various adjustments were inductively made, with the sub-code being partly adapted to the evidence emerging from the data.

In this process, I wrote memos during the coding-stage, which helped me recall and strengthen ideas, to relate the codes to categories and it helped me during the formalizing of the results (Charmaz and Bryant, 2010). In total I wrote 56 memos: 35 memos related to codings, 7 memos related to the codes, and 14 memos related to the interview document. I also noted ideas in a separate memo document, which at the end of the whole process was 40 pages long.

Once I finished the coding process, I described and synthetized the data. This enabled a second comprehensive review process. In this process, the codings, codes and code categories were checked again.

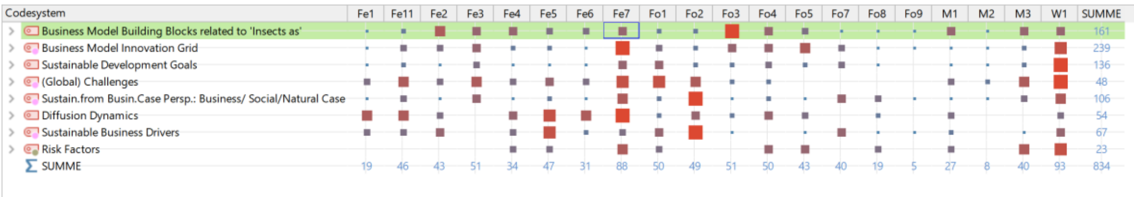

Figure 31: Overview of total Code Categories and Codings

As a final result of the coding process, 8 code categories were created, which are consistent with the strategic guiding dimensions. These code categories comprised 207 codes (see Appendix 8). The codes correspond to the dimensions and features of the morphology in principle. They, however, punctually diverge because the interview analysis revealed new aspects. In total, the codes cluster 834 codings. Figure 31 provides an overview of code categories and related codings.

TYPOLOGY DEVELOPMENT

To develop the typology, I focused on the strategic guiding dimension that - as a result of the data synthesis - was the most insightful. This applied to the dimension of 'Business Model Innovation Grid' and its mechanisms for sustainable business model innovation. The theoretic fundament of the Grid was built in section 2.5.2 and the data synthesis is provided in section 4.3.2.

I bundled the mechanisms regarding central commonalities. These commonalities are composed of two Morphology dimensions, namely the ‘Innovation Object’ and the ‘Type of Customer’. To structure the process, I created a table and began provisionally bundling the mechanisms. This resulted in four bundles.

Two bundles of the four related to innovation objects: one bundle relates to (1) ‘Products’ as innovation object, namely food, feed, fertilizer/compost. The other bundle relates to (2) ‘Processes and Technology’ as innovation objects. The remaining two bundles were both related to the Morphology dimension ‘Type of Customer’: (3) one relates to Producer (B2B), more precisely to producers while the other bundle relates to Final Consumer (B2C), more precisely to final consumers.

At this point of development, the table of the typology consisted of 5 columns and three rows. The columns comprised the dimensions of the typology (column 1) and its respective types (column 2-5), and two rows comprised the central commonalities related to the two Morphology dimensions (innovation object and type of customer) and the third row comprised the ‘mechanism of the business model grid.’ Once the commonalities were consistent; I added another two rows: one which shortly describes each type and another which labels them. The result is described in 4.5.

4.3 DATA SYNTHESIS

The data from the 20 analyzed interviews produced a great wealth of data. To structure, analyze and summarize the data, they are clustered according to code categories created in MAXQDA. These categories match with the dimensions presented in Table 8, which refer to ‘dimensions for assessing business opportunities.’

Each code category is individually analyzed in this section. The analysis includes describing the data while concentrating on aspects of sustainability, and visualizing the relation between code categories (and subcategories) and codings by means of a MAXQDA code-matrix-browser (CMB) or code-relations-browser (CRB). At the end of this section, a summary is provided.

The data synthesis also serves to empirically assess the morphological dimensions and features and to check which of them are useful for characterizing the Insect Economy and which are dispensable. The required modifications of the Morphology are indicated at the end of each section, and its updated version is depicted in section 4.4.

4.3.1 BUSINESS MODEL BUILDING BLOCKS APPLIED TO ‘INSECTS AS’ AND RELATED SUSTAINABILITY ARGUMENTS

As a result of the coding process (see Figure 32), four ‘insect as’ categories were created. They are as following: (1) ‘Insects as Food,’ (2) ‘Insects as Feed,’ (3) ‘Insects as Organic Waste Converters,’ and (4) ‘Insects as Pet Food, Fertilizer, and Raw Material.’ The latter (4) is a category that groups these value propositions (Pet Food, Fertilizer, and Raw Material).

Most codes were assigned to the categories Insects as Feed, Insects as Food and Insects as Organic Waste Converters (85 percent). Therefore, in the following subsection I further elaborate on value propositions of these categories. Furthermore, the interview partners were asked to explain the reason they chose the value propositions of their business model. As is shown in the subsequent subsection, the reasons are often linked to sustainability aspects, and for this reason this aspect is explicitly addressed. At the end of this subsection, the findings are summarized.

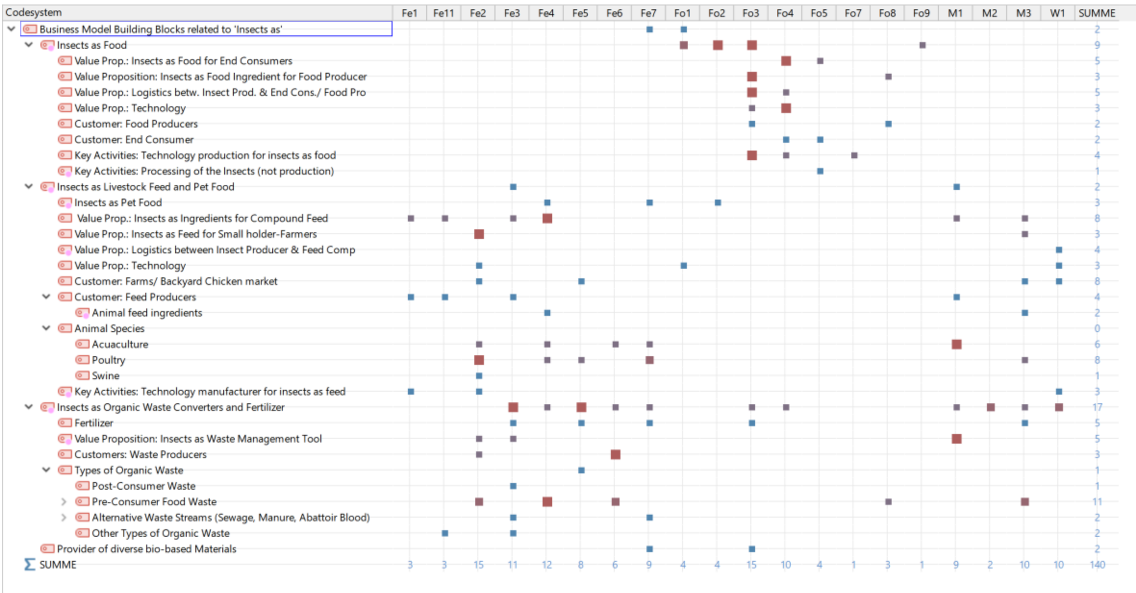

Figure 32 Codings related to 'Insects as'

VALUE PROPOSITIONS

Value propositions in the 'insects as livestock feed and' space consist of insect rearing technology, insects as feed ingredients, insects as feed for small-holder farmers or backyard chicken owners and for pets specifically cats and dogs, and logistics solutions. An example of a logistics solution is as follows:

> *"We are the hatcheries supplying the hatchlings to farmers, we are the distribution standard that drops of the food waste [from restaurants] at the farm, and we design the equipment that the farmer can then lease or purchase." [W1_16]*

Value propositions in the 'insects as food' space consist of technology to produce insects, insects as food for end consumers, insects as food ingredients (in the form of protein powder) for food producers, and logistics concepts. An example of a logistics concept is as follows:

> *"We sell whole solutions to the farm for a certain amount. First, we sell the equipment and the insects to the farm. Then we provide insect feed, sell support and how to do the maintenance, and then we buy everything back what they produce." [Fo3_ 93]*

Regarding ‘insects as organic waste converter and fertilizer’ space, the value proposition refers to converting different types of waste into biomass and to use the insect frass as organic fertilizers. In regard to organic waste conversion., entrepreneurs distinguish between pre-consumer waste, post-consumer waste, and alternative waste streams (i.e., sewage, manure, abattoir blood). Thus, target groups are organic waste producers such as food and beverage producers. Regarding insect frass, most companies are still evaluating to sell it as organic fertilizer.

The code category “insects as Provider of diverse bio-based Materials” has assigned the least codings. The reason might be that the focus of producers is still mostly oriented on insects as food and feed as bio-based materials are confronted with factors of diffusion dynamics which hinder their introduction. However, further analysis is required to better understand this aspect.

Since describing the products by activity (in 3.5), it was clear that the business models in this sector have multiple value propositions. This is also reflected in the coding results (see again Figure 32). Only four out of 20 companies (20 percent) are clustered into only one category: three operate only in the insects as food space, and one operates in the insects as feed space only. These companies are likely to have considered selling the insect frass as fertilizer, but did not do it yet due to their limited capacities during the venture creation process. 40 percent of the 20 companies span across three categories and more. For example, venture Fe2 sells insect rearing technology to produces insects as feed. It offers insects as animal feed for small-holder farmers and uses insects as a waste management tool.

Drawing again on Figure 32, it becomes evident that ventures in the insects as food space rarely use organic side-streams as insect feed, whereas this is more common in the insects as feed space. A dominant reason behind this pattern is that using organic waste as feed for insects may discourage consumers from eating insects, which by itself requires courage by many consumers.

Using organic side-streams as feedstock for insects, however, is an essential argument for sustainability. On the other hand, using insects as feed would support conventional animal farming practices, which were identified as a root cause of global challenges (see page 120). An overview of the value propositions is provided in Appendix 8.

The scope of this research lies on ‘insects as food,’ ‘feed’ and ‘organic waste conversion’ because ventures in these fields seem to be aware of sustainability issues. Therefore, it is relevant to understand why entrepreneurs decided to enter either one or the other sector. This aspect is addressed in the following subsection.

INSECTS AS FOOD VS INSECTS AS FEED: WHAT IS MORE SUSTAINABLE?

During the interviews, the entrepreneurs were asked about their motives of entering the ‘insects as food’ or ‘insects as feed’ space. As Figure 33 shows, they had different reasons for choosing either one or the other.

While some producers had pragmatic business motives (e.g., “I think that when we were looking at the microeconomic data […], it was really feed-oriented and we were more interested in a large-scale operation." [Fe11_59]). Others, however, provided arguments related to sustainability to enter one of the two business spaces.

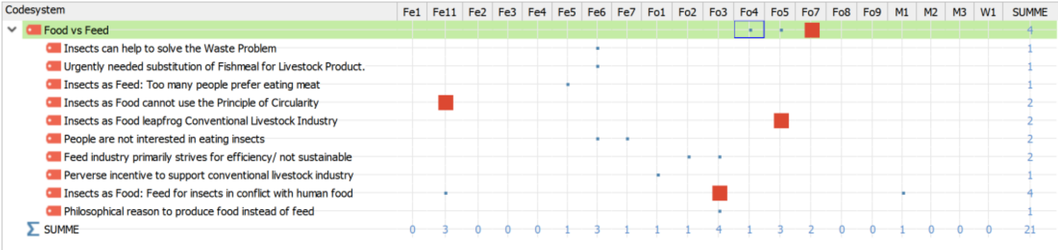

Figure 33: Insects as Food vs Insects as Feed

Insects as food producers described their arguments as following

> *Feed is a completely different area. In order to compete to become a big player in the feed market, you have to be very very efficient. Then you talk about commodity and very low costs, and you need a lot of money for that. We know that our competitors raise a lot of money. The ones in the feed industry, - we had a chance to talk to some of their investors. The basic concept of what we do comes from looking for a healthier protein alternative for humans. [Fo2_116]*

> *What is the point of rearing insects on plant substrates, which we then feed to animals and then eat these animals ourselves, if we could eat the insects without further ado? [Fo5_107]*

> *We are not particularly keen on feed and […] I am specifically talking about livestock feed. When I am thinking about companies that are rearing black soldier flies the problem is you complete with soy protein, and soy protein is $300 per kilo. For you to somehow replace soy protein with insect protein, you have to achieve cost efficiency that is near impossible. I am not saying that it cannot be done - maybe with a few hundred million dollars and seven more years, it is conceivable. For the meantime and the long foreseeable future, anybody who is competing in the insects-for-feed business is pretty much a supplement not a substitute. In other words, if I were a fish farmer, instead of throwing four hands full of soy protein for my fish, I going to throw three hands full of soy and one hand full of insect protein. Now, why is this problematic philosophically all together? I am trying to actively find ways to make it cost effective for a livestock farmer to breed more livestock then I am actually perpetuating an existing problem. Now, in cattle production, most of my cost is the cost of feed. [4:44] When [company x and y] and whoever else comes to me and says 'I can offer you cheaper feed than soy,' I would be very happy. Now I can raise more cows and more chicken because I can afford to do that because the cost of food has gone down. And that is ironic because you are providing more sustainable feed to feed a very unsustainable livestock. So, you are positively reinforcing an industry that is actually environmentally damaging. Whereas what we are doing as positioning it is food. We are saying 'no'. We are hoping that you can shift your diet away from this livestock a little bit, we are not naive. We are not going to stop eating meat*

> *tomorrow. We are not stopping people from eating meat at all. We are telling people, instead of five or six or seven times a week make one or two of those days insects. [Fo1_96]*

Thus, the ‘insect as food’-producers argue that their value offerings leapfrog the whole problem of the food value chain by offering more sustainable food products and by incentivizing more sustainable consumer behavior. They further argue that the feed sector can hardly be sustainable due to the pressure to increase efficiency. Another argument is that by producing cheaper feed products, the company would incentivize the meat industry further – an industry that they understand requires substantial change.

‘Insect as feed’-producers counter these arguments as follows:

> *Obviously [we entered] the feed market and not in the food because in the food market you allow some people to shift from beef or chicken, or whatever animal protein to insect protein and lower our footprint. But the way you feed your crickets or your locusts or whatever, I think you do not have this cradle to cradle process, you are not in the Circular Economy, you have to buy feed to feed your crickets and things like that. It does not fit our way of seeing sustainability and Circular Economy and environmental change. [Fe11_63]*

> *I think it is only about 5 percent of the American populous that doesn't eat meat. 95 percent of Americans are eating meat. So, I think it is important to recognize just the realities of the world, which is chicken and pork and beef are delicious and people love to eat them [Fe5_119]. What we are doing is displacing something that currently exists. The metrics look at: How much organic matter we are able to keep in our food system as opposed to going to landfill. Or how much foreign soy we have been able to displace with insects in feed. Or how much fishmeal we have been able to displace in the production of fish. So I think to have an impact really it is going to take a lot of scale. [Fe5_130]*

> *The thing is that there is a very big psychological gap for people to eat insects in Brazil. Brazilians might start eating insects in 30 years from now - at a large scale. […]. Feed would be shorter to be established. The other reason is […] that we need to find a solution to fishmeal. […] If we treated ten percent of all the organic waste produced in this country, we would potentially produce all the insect meal needed to supply the planet. [Fe6_93-5]*

Thus, the ‘insect as feed’-producers argue (1) that they can close production loops and establish a Circular Economy, which in their view, would not be possible in the ‘insects as food’- market (Company Fo8 is an example that a Circular Economy with insects as food is possible). Another noticeable argument is (2) that there exists a limited cultural readiness to consume insects as food and, therefore, a business model in this field is not viable in every cultural region. Moreover, finally (3), they argue that there is a huge demand for meat and that the industry requires support to make a shift towards more sustainability.

Some entrepreneurs recognize that farmers are striving for more sustainability (Fe5) and aim to support their endeavor. Other entrepreneurs are promoting a shift from within the system by changing the power structures because they understand that globalized value chains put too much pressure on farmers to achieve sustainability. A US American feed producer explains how the system currently works:

> *“the [conventional] types of chickens you can grow to a full meat bird takes about six weeks. But that model - that six-week model - what it also does, it really bankrupts the farmer because what happens is that he does not own the chicken. [The multinational food corporation,] Tyson[38] owns the chicken. The farmers also don’t own the feed. Tyson owns it. But you need it to supply all of these birds, and you have all of these infrastructure costs. And if you do not keep up with Tyson’s contractual terms, they start giving you lower quality feed, and lower quality birds […] this whole contract farming of the American farmer […] is providing labor, that is it! It is their farm, their debt; those poultry farms are worth nothing once they are built. […]. So this whole Tyson-chicken-phenomena – yes, the chicken is very efficient in the sense that it is six weeks until it is grown - but what's going on is that you can have a low-quality food.” [W1_62]*

Through his business model, the company W1 provides the farmers with ‘feed autonomy’ by which farmers can rear their own insects and feed them to their chicken. The chickens are replaced by ‘heritage birds’ which “can both be used for meat and eggs” [W1_62]. This example shows the way the insects-as-feed producers produce a bottom-up system change.

In conclusion, from the interview responses, it can be deduced that ‘insect as food’-producers tend to promote more disruptive change as compared to ‘insect as feed’-producers. The former aim to promote lifestyle changes by revolutionizing eating habits of consumers, while the latter aim to improve the current system. However, also the ‘insect as feed’-producers offer solid arguments for their contribution towards sustainability. They aim to close loops by fostering a Circular Economy and triggering system change through novel business models.

SUMMARY

Business models were categorized into insects as food, livestock feed and pet food, and organic waste converter and fertilizer, and provider of diverse bio-based materials. Related to these categories diverse value propositions were identified. Through the analysis it became evident that the first three categories (‘insects as food’, ‘insects as livestock feed and pet food’, ‘insects as organic waste converters and fertilizers’) are dominant in the sample. However, the analysis also showed that even though these categories dominate in the sample, the business models usually combine value propositions of two or more categories.

---

[38] Tyson Foods, Inc. is an American multinational corporation based in Springdale, Arkansas, that operates in the food industry. The company is the world's second largest processor and marketer of chicken, beef, and pork after JBS S.A. and annually exports the largest percentage of beef out of the United States. (Wikipedia, 2017)

Both, in the ‘insects as livestock feed and pet food’ and in the ‘insects as food’ space, dominant value propositions are insect rearing technology, logistics solutions, insects as feed or food ingredients either for end consumers or food or feed processors. In the ‘insects as organic waste converter and fertilizer’ space, the value proposition refers to converting pre-consumer waste, post-consumer waste, and alternative waste streams (i.e., sewage, manure, abattoir blood) into compost. Advanced business models use a circular approach and convert insects into feed (and in one case into food).

Furthermore, the data description also drew on personal motivation of entrepreneurs to enter either the food or the feed sector. The motivations included rational arguments for their decision and (very passionate) arguments for sustainability. The arguments of both ‘insect as feed’-producers and ‘insect as food’-producers are solid and led to the conclusion that a better way to judge their contributions would be to see them as complementary. Both food value chains and consumer behaviors need to change to create a sustainable future.

Regarding the morphology, the dimension ‘Insects as’ is updated as follows: the feature ‘insects as organic waste converter” is extended to “insects as organic waste converter and fertilizer.” The feature “natural enemies and pollinators” was not part of the sample selection. The results of heading 3.5 showed that this features is relevant which is why it remains in the morphology.

4.3.2 BUSINESS MODEL INNOVATION GRID: SUSTAINABLE STRATEGIES AND MECHANISMS FOR SUSTAINABLE BUSINESS MODEL INNOVATION

In section 2.5.2, the Business Model Innovation Grid (former Business Model Archetypes) was introduced. It consists of dimensions, sustainable strategies and mechanisms for sustainable business model innovation. Using the Business Model Innovation Grid was identified as useful for a refined identification of the unique sustainability characteristics of the business models. For this reason, this tool is used to structure and analyze the interview data (Bocken et al., 2014, Centre for Industrial Sustainability, 2014).

At first, I describe the general findings and the way the Grid – specifically the sustainable strategies and mechanisms for sustainable business model innovation – fit(s) the business models of the Insect Economy. Then, the shortcomings of the Grid are addressed, and solutions are introduced to overcome them. Finally, a summary of the findings is provided at the end of this subsection.

GENERAL FINDINGS RELATED TO THE BUSINESS MODEL INNOVATION GRID

The higher-level structure of the Business Model Innovation Grid consists of three dimensions. These are the technological, the social and the organizational dimension. The business models in the Insect Economy span across all three of them.

These dimensions contain eight sustainable strategies (former archetypes) that cluster the mechanisms for sustainable business model innovation. Out of these eight strategies, seven could be identified in the Insect Economy. Those are Circularity, Substitution with Renewables (grouped under the technological dimension), Functionality, Stewardship, Slow Consumption (grouped under the social dimension), and Co-Creation and Social Entrepreneurship (both grouped under the organizational dimension).

Surprisingly the most basic sustainable strategy, namely that of Optimization, could not be identified through the analysis. However, it can be assumed that business solutions based on optimization are also prevalent in the Insect Economy. The following quote from an interview partner shows this “this is a new field, so we are not efficient enough to compete with industries such as beef or poultry which has been existing for many years” [Fo2_98]. However, no specific sustainable solution or mechanism could be identified.

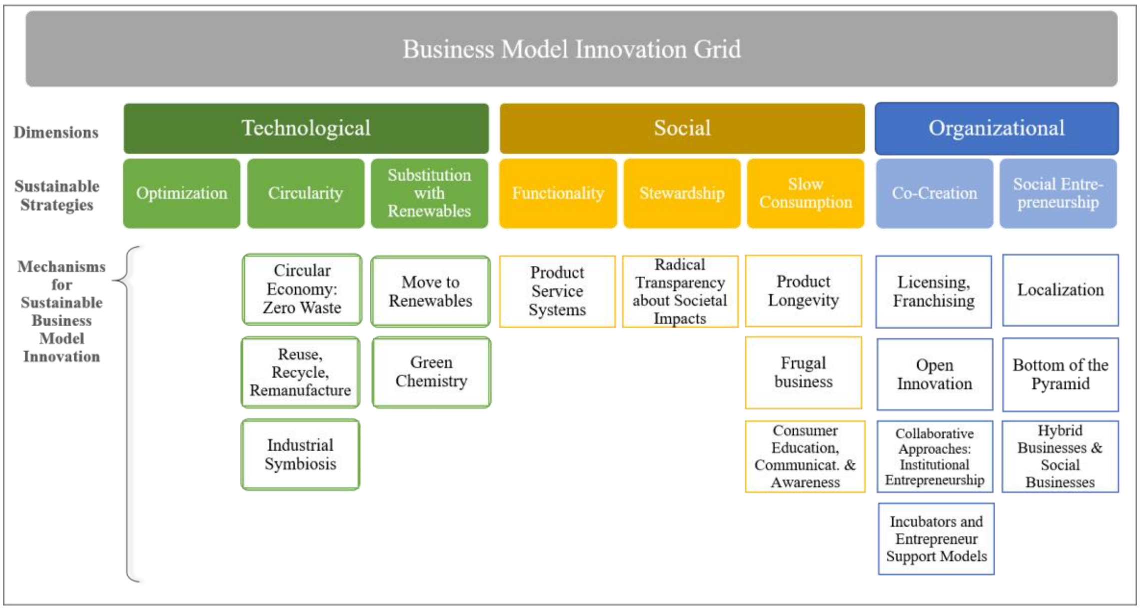

Figure 34: Business Model Innovation Grid: Mechanisms for Sustainable Business Model Innovation identified in the Insect Economy
Source: Adapted from (Centre for Industrial Sustainability, 2014)

The sustainable strategies cluster 52 mechanisms for sustainable business model innovation (Centre for Industrial Sustainability, 2014). Through the interview responses, 17 out of 52 mechanisms could be associated to the business model in the Insect Economy: Five mechanisms could be associated to the technological dimension, 5 to the social dimension, and 7 to the organizational dimension. Figure 34 provides an overview of the identified mechanisms in the Insect Economy. The fact that the organizational dimension leaps out of the other two dimensions shows that the ventures try to implement alternative paradigms in their way to do business (cf. Boons and Lüdeke-Freund, 2013).

The sustainability of a business model can be mapped using the Grid. Indicators for a sustainable business model are (1) the number of mechanisms a business model combines. The more it uses, the more sustainable it is. Ideally, the mechanisms (2) span across multiple sustainable strategies and dimensions and (3) affect multiple business model building blocks (Bocken et al., 2014).

In effect, in the Insect Economy, such comprehensive business model innovations are prevailing. Figure 35 visualizes that 148 codings could be assigned to the mechanisms of sustainable business model innovation. Particularly many codings were assigned to the mechanisms ‘Collaborative Approaches: Institutional Entrepreneurship’, ‘Industrial Symbiosis,’ ‘Circular Economy: Zero Waste,’ and ‘Circular Economy: Modularity.’

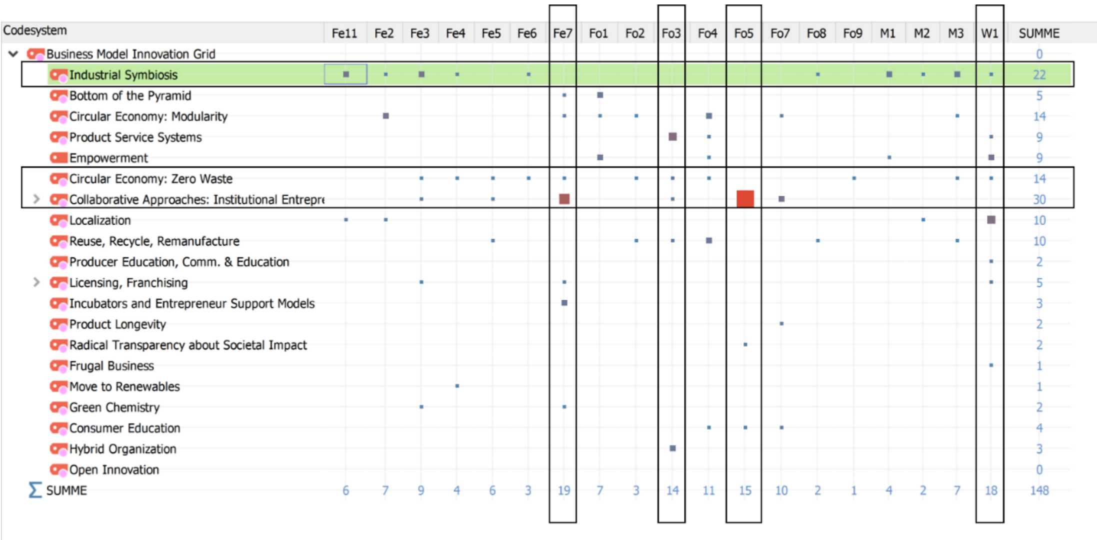

Figure 35: Business Models based on Insects related to Mechanisms for Sustainable Business Model Innovation

Note: The frames highlight (1) the ventures that most mechanisms use and (2) the mechanisms that are most used in general.

No code was assigned to the mechanism ‘Open Innovation.’ The reason is that there was no mentioning about open innovation projects by the interview partners. However, the literature research has shown that ventures in the Insect Economy, particularly in the scope of this research participate in numerous research projects. Examples are the ChitoTex EU project, BioConVal, PROteINSECT, Project Desirable and InnSecta. For that reason, the mechanism was kept even though it could not be reflected in the interview responses.

On average, 3.4 mechanisms were identified per venture.[39] Six out of 20 ventures stand out for using more than four mechanisms for sustainable business model innovation.

- Among these is the business model of company Fe7 which uses the following six mechanisms: (1) Circular Economy: Zero Waste, (2) Collaborative Approach: Institutional Entrepreneurship, (3) Incubator and Entrepreneur Support Model, (4) Bottom of the Pyramid, (5) Green Chemistry, and (6) Licensing, Franchising.
- The second good practice example is company Fo3 which combines (1) Circular Economy: Zero Waste, (2) Collaborative Approaches: Institutional Entrepreneurship, (3) Product Service System, (3) ‘Hybrid Businesses & Social Businesses,’ (4) Reuse, Recycle and Remanufacture, and (5) Industrial Symbiosis.

[39] The result of an average of 3,4 mechanisms per venture result are binarized. Then instead of 148 codings, there are only 68/20=3,4.

- Moreover, the third good practice example is company W1 which combines the following mechanisms: (1) Circular Economy: Zero Waste, (2) Product Service System, (3) Frugal Business, and (4) Industrial Symbiosis, (5) Localization, and (6) Licensing, Franchising.

The examples show that the combinations are very different, which gives an idea about the distinction between the business models and the degree of innovativeness in the sector.

In conclusion, the dimensions and sustainable strategies of Bocken et al. (2014) could widely prove relevant to assess and classify the Insect Economy. All dimensions are covered by the Insect Economy, and seven out of eight sustainable strategies could directly be proven. Furthermore, 17 out of 52 mechanisms for sustainable business model innovation could be identified in the 20 business models. An overview of the identified mechanisms, their definition and corresponding responses from the interview partners is provided in Appendix 9.

SHORTCOMINGS

Bocken et al. (2014) identified and categorized the elements of the Business Model Innovation Grid mainly from the literature. When analyzing the business models described by the interview partners according to the Grid, the mechanisms did not entirely fit the empirical evidence. The lack of fit applied on three occasions. In these occasions, it was suitable to create new mechanisms. Those were termed (1) Empowerment, (2) Circular Economy: Modularity and (3) Producer Education, Communication & Awareness. Figure 36 gives an overview of the complemented mechanisms. The following subsection provides further information about the new mechanisms.

CREATION OF NEW MECHANISMS IN THE FRAMEWORK THE BUSINESS MODEL INNOVATION GRID

This subsection explains the reason for the creation of new mechanism being suitable to fit the business models of the Insect Economy. To do so, the new mechanisms are related to already existing ones and are explained how they differ from each other.

CIRCULAR ECONOMY: MODULARITY

Modularizing is an important design aspect of insect rearing technology. As was described earlier (see page 94), this approach is used to increase efficiency and upscale production. Modularity is a core design aspect of the Circular Economy (Ellen Macarthur Foundation, 2013). A mechanism of the Business Model Innovation Grid that comes close to this aspect is ‘Circular Economy: Zero Waste.’

The Centre for Industrial Sustainability (2014) defines this mechanism as a business model approach by which “products and business processes are designed in a manner that enables waste at the end of the use phase of a product to be used to create new value.” The definition shows that the design aspect of modularity is not explicitly part of this mechanism.

Modularity refers to designing products or systems in a way that they are relatively independent, but that their components or parts are interlocking (Ellen Macarthur Foundation, 2013). It is, therefore, a fundamental product design principle to achieve the circular design together with purer material flows and design for easier disassembly. Modularity enables easy versatility, scalability, and adaptability. In the business context, this means more flexibility for innovation and the development of diversified value chains (WEF, 2014b).

Dominant solutions in the Insect Economy that apply to this mechanism are shipping containers and rearing facilities that fit existing buildings. A North American feed producer for instance uses "Container solutions particularly for food and beverage processors" [Fe2_92] and a European insects-as-food producer uses both, "shipping container or existing buildings" [Fo4_15]. A number of entrepreneurs are planning to use the modular approach to expand their business (globally).

PRODUCER EDUCATION, COMMUNICATION & AWARENESS

Sustainable future requires radical shifts in lifestyles and in the way goods and services are designed, produced and used (Meadows et al., 2004). The aspect of lifestyle changes and consumption patterns is covered in the Business Model Grid by the mechanism 'Consumer Education, Communication & Awareness.' According to the Centre for Industrial Sustainability (2014), the latter refers to "sensitizing consumers about the impact of their purchases. It induces consumer activism that is based on the

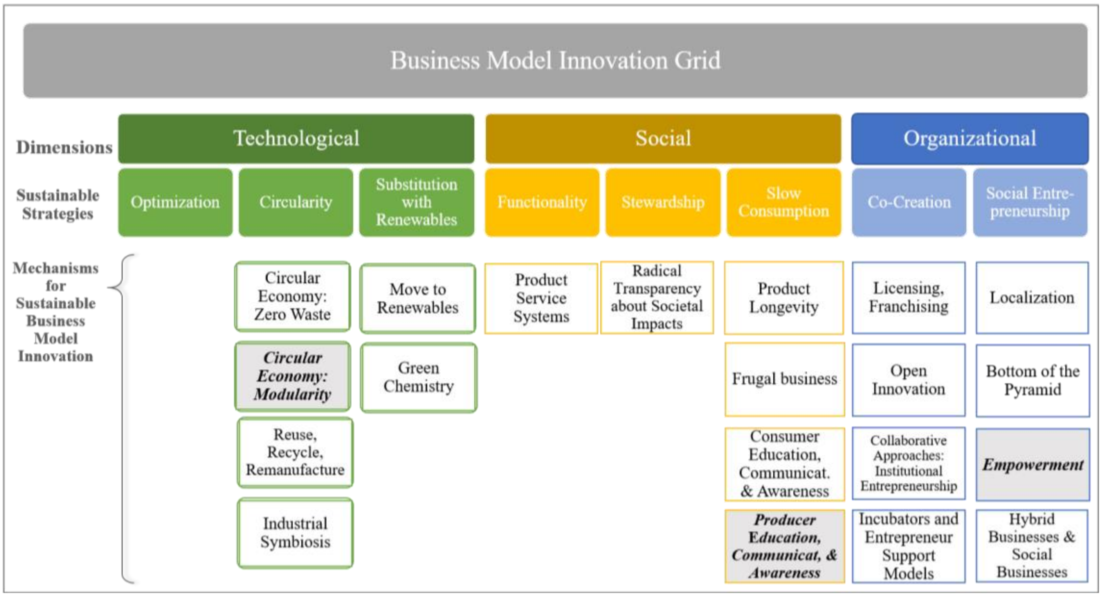

Figure 36: Business Model Innovation Grid: Complemented Mechanisms for Sustainable Business Model Innovation to overcome Shortcomings
Source: Modifications are highlighted in italics and grey shadowed.

concept of dollar voting."

Indeed, in the Insect Economy, this mechanism is used by a number of start-ups who educate consumers through social media campaigns (e.g., Fo1, Fo4, Fo5), public presentations (Fo5) and through the product message itself. Regarding the latter, a product designer states that "[our product] is supposed to show that you can feed yourself a bit outside of your habitual food ideals, or a bit outside of the comfort zone, even with insects or whatever" (Fo7_75).

However, one entrepreneur (W1) changed the focus and addressed the issue of educating *producers*. This focus group differs regarding its needs, and in the way, it can influence the marketplace. Therefore, a new mechanism was created namely '*Producer* Education, Communication & Awareness.'

Company Fo1, Fo4, and Fo5, which educate consumers, position their sustainable offerings in the upper segment of the market allowing them to pass on the higher costs of sustainable practices to consumers and balance the triple bottom line. Thus, these ventures can translate their primarily environmental goals into customer benefits. This enables them to compete on quality, not on price (Belz and Binder, 2015).

Such an approach is more challenging for producers than for consumers. They have to adapt to the customers' value perception of the product benefits and the customers' purchasing power (Customers Willingness to Pay). Hence, even though, producers are aware and interested in creating social and environmental benefits, they require a strategy to align economic success and sustainable (non-monetary) activities. Such a link can be created through a *business case for sustainability*.

A North American Entrepreneur describes the business case he enables as following:

> *"Another great example that I use from a marketing perspective is every 20 to 25 liters of food waste that we pick up brings back one dozen eggs. And suddenly that image of [our product] is that it brings back a dozen eggs, versus I educate them. Then I explain that if we were to compost that amount of waste, we would create about 20 cents of compost or a dozen eggs. And so, they see that huge shift in valuation between making compost and making food. Because it has to happen so close to the city, the food waste producers provide nutrients to local farmers." [W1_74]*

In addition to the business case, the marketing strategy for the sustainable solutions plays a role in this mechanism of *Producer* Education, Communication & Awareness. Belz and Binder (2015) found that if a company cannot clearly align social or ecological attributes with core purchasing criteria such as functionality, performance, design, durability, taste, or freshness the company has to make an extra effort to sensitize consumers to the sustainability issues. Thus, the socio-ecological attributes need to be tied to the customer benefits.

Consequently, producer education and consumer education require different approaches to be successful. While consumers can influence their purchasing decisions through their personal choices, producers cannot assume private costs for the long-term. Therefore, their sustainability-orientation needs to be supported by economic arguments.

EMPOWERMENT

Poverty and inequity were earlier identified as great challenges of society. These challenges are often associated with survival economies with the poorest population across the world (Hart and Milstein, 1999). This form of poverty is represented as 'Bottom of the Pyramid' (BOP) in the Business Model Grid, which refers to markets where people live on less than 1.90 dollars per day. Thus, the intention with the Bottom of the Pyramid-concept is to endow the very poor by giving them access to markets. In the Insect Economy, some businesses focus on BOP markets as the following quote exemplifies:

> *"In [Africa], we have four villages in which we work. Each village has about 125 farmers who work with us. The idea is that we give them an individual farming equipment, which allows them to produce maybe two or three kilos of palm weevil larvae. That is enough for most people to just feed them and their own family. But we have a few farmers, 20 percent of the 500 farmers, who are very motivated and who set up multiple small farms. So instead of buying just one or two kits, they bought ten kits to produce 20 kilos trying not to serve only their own family, but they are now selling to their community" [Fo1_91]*

However, poverty and inequity cannot be expressed only in economic terms since it is related to improving peoples' choices and their active participation in society. Deprivation from this basic need can also be experienced in countries with a high human development index. In this context, the Bottom of the Pyramid-Concept is inappropriate. A better-fitting alternative is the concept of '*Empowerment.'* Interview partners employed the term by referring to farmers in North America or Finland, who find themselves confronted with fierce price pressure. The following quote exemplifies the concept:

> *For example, in Finland, our traditional farmers (family farmers) are suffering because the prices of meat are really low and they cannot live without European Union's support. The farming business is not profitable in Finland, but farmers are always looking for new businesses in order to survive in the countryside. So this is one possibility in how we create benefits for people. […] So we sell whole solutions to the farm for a certain amount. Then we also sell support and how to do the maintenance and then we repurchase everything that they produce. [NE_96]*

Thus, in the context of the Insect Economy, the term refers to improving the market power of underprivileged businessmen, particularly in wealthy countries to improve their choices, to reduce inequality and to enhance their active participation in society.

Furthermore, from a business model perspective, the Bottom of the Pyramid- concept and the Empowerment-concept require different solutions because both target groups – be it as customers or partners - have fundamentally different needs. This is a central aspect of business model innovation recalling that business models are tools to articulate the logic about the way it delivers value to customers. Thus, the customer segment is a starting point for business model innovation and produces different value propositions depending on their needs.

SUMMARY

The data analysis related to the Business Model Innovation Grid produced the following core findings: First, the dimensions and sustainable strategies of Bocken et al. (2014) could widely be proven to be relevant to assess and classify the Insect Economy. All dimensions are covered by the Insect Economy, and seven out of eight sustainable strategies could directly be proven. Furthermore, 17 out of 52 mechanisms for sustainable business model innovation could be identified in the 20 analyzed business models. Second, the empirical evidence detected shortcomings because the mechanisms did not entirely fit the empirical evidence. Third, to overcome these shortcomings, three new mechanisms were introduced. Those were termed (1) Empowerment, (2) Circular Economy: Modularity and (3) Producer Education, Communication & Awareness.

In conclusion, the Business Model Innovation Grid is a useful tool to classify business models in the Insect Economy. A detailed table of the identified and added mechanisms, their corresponding definition and responses by the interviewees is provided in Appendix 9.

The mechanisms for sustainable business model innovation are updated in the morphology.

4.3.3 SUSTAINABLE DEVELOPMENT GOALS AND THE INSECT ECONOMY

As a result of the literature research in Chapter 3, it was identified that the Insect Economy has the potential to contribute to 10 out of 17 Sustainable Development Goals (SDGs). Through the interview analysis, these findings could be widely confirmed. Even though the interview partners did not directly refer to the SDGs, the responses corresponded with the content of the goals[40]. Only one interview partner actively mentioned the SDGs, stating that

> *"When you look at the Sustainable Development Goals - most of them can be addressed by insect protein. I love the set-up of the Sustainable Development Goals because it is not too complex, but it is not oversimplified either. It is very easy to simplify sustainability into one or two statements so I think the framework can do for many companies and initiatives to see where they can have an impact" [Fe1_73].*

Out of the 10 SDGs, those with the most correlations are SDG 9: Industry, Innovation, and Infrastructure, SDG 12: Sustainable Consumption and Production, and SDG 14 and 15: Live below Water and Life on Land. Those with none or very view correlations are SDG 1: End Poverty, SDG 2: Zero Hunger, and SDG 3: Good Health and Well-being. In addition, SDG 7: Affordable Energy is not addressed. This result was

[40] Facts and figures, goals and further links about the SDGs are provided under this link: http://www.un.org/sustainabledevelopment/sustainable-development-goals/.

expected because producing energy from insects is still not an economically viable solution (see chapter 3).

Addressing SDG 1, 2 and 3 by using insects was at the core of the report of 'Edible Insects: Future Prospects for Food and Feed Security' (Van Huis et al., 2013) to fight hunger, malnourishment, and poverty. For that reason, the fact that these are almost not addressed by the ventures is somewhat disappointing. However, the reasons the companies are not addressing these problems are multiple: on the one hand, entrepreneurs argue that exporting to these countries is still not economically viable and that export is restricted [Fo2_77]. On the other hand, some entrepreneurs see a moral responsibility to begin delivering their products in industrialized countries where the most substantial impact is caused. One of them argued as follows:

> *"we could put a few containers in developing countries where they look pretty nice and that we are helping poor. But if you really think about the sustainability in a global angle: about the rich folk in the western countries and then the middle class in the developing countries who are using more and more protein. We have to convince them to make an impact." [Fo4_46]*

In regard to SDG 3: Good Health and Well-being, entrepreneurs in the food sector clearly use the nutritional benefits of insects as a marketing tool. Yet, a part from company Fo1 and Fe7 which address BOP markets, the remaining ventures are selling elaborated products such as burgers and protein bars positioning their products in the upper price segment and targeting consumers in consumerist economies. Thus, poor and malnourished people in developing countries are in most cases not accessing these products. It is, however, these individuals who should be targeted according to SDG 3.

NEWLY IDENTIFIED SDGS THROUGH DATA ANALYSIS

Apart from the SDGs identified during the literature research, three additional SDGs could be identified, namely SDG5: Gender Equality, SDG 8: Decent Work and Economic Growth, and SDG 10: Reduced Inequality. These are addressed in further detail in the following paragraphs.

SDG5: Gender Equality refers to providing women and girls with equal access to education, health care, decent work, and representation in political and economic decision-making processes. Two entrepreneurs stand out for their contribution to gender equality. Company Fe7 [143-145] provides professional training specifically to women and offers them professional opportunities. Company Fe11 [82-84] created a special working environment for women, where they can take their children to kindergartens. Furthermore, they provide them with flexible working hours for the childcare.

SDG 8: Decent Work and Economic Growth refers to creating jobs that are compatible with local culture and products offering decent working conditions. The feed company Fe3 [16] states that their "*first commercial fly factory [offers] job opportunities and skills transfer to a great number of unemployed people. By earning an income, they are able to support their families*." Another entrepreneur said "*We have internal policies: Wage policies, parity between women men and women, etc. [...] in Brazil* *these concepts are totally foreign to this culture or at least come out seen as non-priority. So, guaranteeing those elements in a company in Brazil maybe is the most challenging of all of these.*” [Fe6_108]

SDG 10: Reduced Inequality refers to empowering the disadvantaged and marginalized population to reduce inequality (within countries). Six companies were identified to contribute to SDG 10 and the means of their contribution are diverse: One approach is to help farmers become independent from current industry structures which undermine their livelihood conditions [W1_16]. Another approach is to support farmers that lost their farms, as the following example tells:

> *"Pig farmers are really hard struck. There were 4000 of pig farms in 2000/2002; now there are only 1000 farms. There are thousands of these pig farms abandoned without being used. So those ex-pig farmers are now looking for alternative ways to use that space and an alternative livelihood. So they are approaching us, saying that this sounds really interesting. So we are retrofitting these abandoned piggeries." [Fe4_18]*

Some entrepreneurs create opportunities for other people to become entrepreneurs themselves, as the following examples shows

> *"You do not necessarily need to give fish to people. You need to teach them how to fish. And that is what [Fo1] is trying to do. They can become their own entrepreneurs. They can find ways to supplement their income." [Fo1_63]*

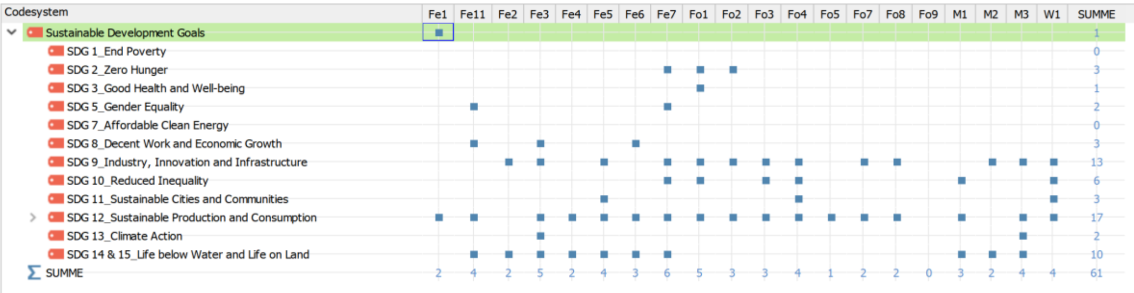

Figure 37: SDGs in the Insect Economy

SUMMARY

In total, 13 Sustainable Development Goals (SDGs) can be addressed by using insects as biological resources (see Figure 37). In addition to the SDGs identified through the literature review, three further goals could be identified (SDG 5: Gender Equality, SDG 8: Decent Work and Economic Growth, SDG 10: Reduced Inequality).

Two SDGs that were earlier identified through the literature research – SDG 1: End Poverty and SDG 7: Affordable Clean Energy - did not emerge from the responses and do not currently appear to be a central concern for the entrepreneurs. Nevertheless, there is potential to address these SDGs by appropriate business solutions. As the focus of this research lies on business opportunities, all SDGs – those that were identified and those that were not identified – are considered as means to discover or create business opportunities in the Insect Economy.

The newly identified SDGs are updated in the modified morphology.

4.3.4 GLOBAL CHALLENGES

As a result of the Morphology development, 12 global challenges were identified that could be resolved by using insects as biological resources. The interview partners made reference to ten of these 12 global challenges. Consequently, they set a strong focus on the issue (1) Environmental Degradation and Depletion of Fish Stocks, (2) Waste Production, (3) Unemployment/ Social Inequality and (4) Malnutrition and Food Scarcity.

While the first, the second and the third issue confirm the findings related to the Sustainable Development Goals, the focus on malnutrition and food scarcity is surprising. Because, in the chapter before, it was stated that SDG 2: Zero Hunger and SDG 3: Good Health and Well-being seem not to be a priority for entrepreneurs. For an overview see Figure 38. Thus, the research findings demonstrate that entrepreneurs are aware of this matter, but because the target market of the interviewed companies in the food sector is consumer economies, no contribution to reaching SDG 2 is made. Perhaps, however, on the medium- and long-term this SDG will be addressed because at least two entrepreneurs stated that they are focused on entering the mass market. Thus, their products might become cheap enough to target developing countries.

The entrepreneurs did not make reference to ‘Resource Scarcity’ as a separate issue from food scarcity. However, they mentioned a new challenge. It relates to the general problems in the Food Value Chain. Entrepreneurs believe that by using insects as feed it would be possible to reduce the medication of animals with antibiotics as well as the problem of fluctuating feed prices by providing insects as animal feedstuff from local production [e.g., Fe11].

SUMMARY

In conclusion, the analysis shows that social and environmental challenges are at the heart of the Insect Economy. In particular, entrepreneurs aim to tackle the issue of waste production, environmental degradation, and social inequality. From a sector perspective on the livestock industry, they recognize the need for a system change. Figure 38 provides an overview of the codes and the quantity of documents the codes are related to.

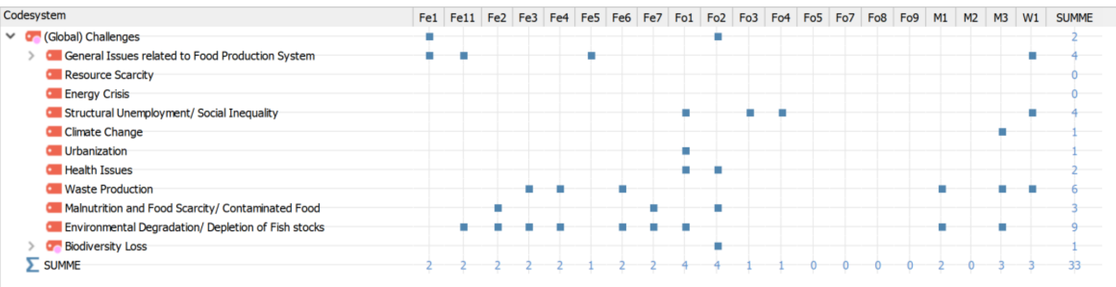

Figure 38: (Global) Challenges and the Insect Economy

In regard to the Morphology, the data synthesis revealed new findings which lead to the following modifications: The features ‘Environmental Degradation’ and ‘Biodiversity Loss’ are combined into ‘Environmental Degradation and Biodiversity Loss’. Moreover, two new features are added, which are ‘Social Inequity’ and ‘General Problems related to the Food Value Chain System.’

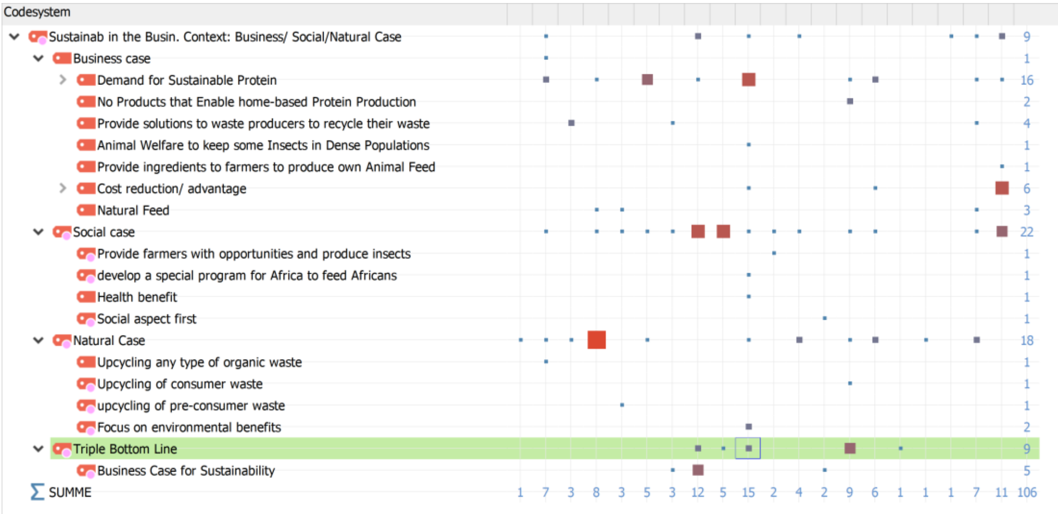

Figure 39: Sustainability in the Insect Economy assessed from the Business Case Perspective

4.3.5 SUSTAINABILITY FROM THE BUSINESS CASE PERSPECTIVE

Assessing the business opportunities from the perspective of the business case, the natural case, the social case and the triple bottom line were too abstract to fit the practical context of the Insect Economy. The attempt to fit the data to these concepts is provided in Figure 39. Even though these concepts do not fit the practical context, they might be useful for the development of the typology. Therefore, the concepts remain part of the morphological grid.

4.3.6 SUSTAINABLE BUSINESS DRIVERS IN THE INSECT ECONOMY

Through the interview responses, 24 drivers could be identified that support the development of the Insect Economy. They could be clustered in five categories, namely drivers related to:

- Sustainability (comprises 8 drivers)
- Insects (comprises 3 drivers)
- Adding Value to Waste (comprises 3 drivers)
- Problems in the Food Value Chain (comprises 6 drivers)
- Other Issues (comprises 4 drivers)

Figure 40: Drivers in the Insect Economy

Figure 40 provides an overview of the categories and their related drivers. Drivers in the code category 'Drivers related to Sustainability' are integrated into the modified morphology. Detailed interview responses related to all drivers are provided in Appendix 10.

4.3.7 DIFFUSION DYNAMICS

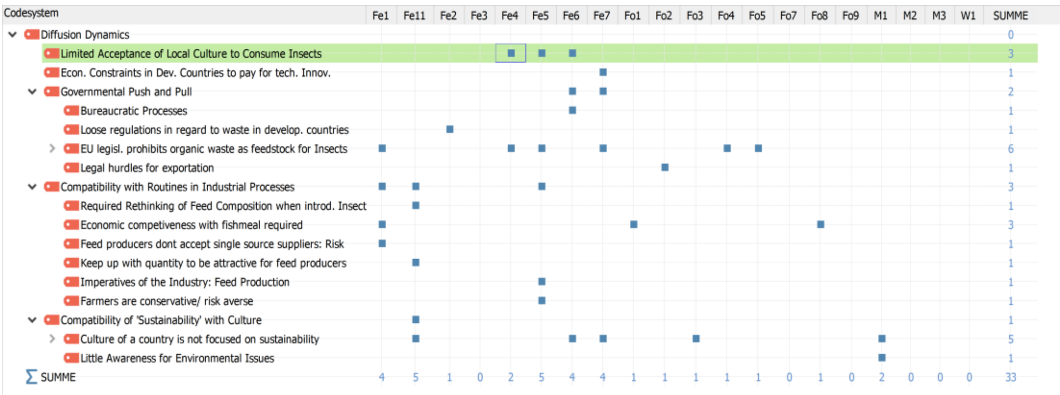

Figure 41: Code Matrix Browser: Diffusion Dynamics in the Insect Economy

Diffusion dynamics describe the "process of imitation and adaptation of an innovation by a growing number of adopters. It comprises the period after the first successful implementation or after market introduction" (Fichter and Clausen, 2016; p. 4). To identify diffusion dynamics in the Insect Economy, I built initially on the influencing factors (2.5.5) from Fichter and Clausen (2016). However, the structure was too general for the Insect Economy. For this reason, I created five categories of diffusion dynamics that are more intuitive and better fit the context of the entrepreneurs. Figure 41 provides an overview of these categories and the related subcategories.

Regulations and Bureaucracy are the most frequently mentioned factors that negatively influence the development of the sector. While one entrepreneur mentioned not to be able to export its products, others make reference to the restrictions by the EU to allow insects as food and feed. This explains the reasons for entrepreneur engagement in changing institutions to engender institutional incentives by influencing industry norms, property rights and laws to enable the sector to flourish (cf. Business Model Grid: Collaborative Approaches: Institutional Entrepreneurship).

In developing countries, the challenge consists of getting sufficient investment to development technology for insect rearing. To date, apart from South Africa where an important venture is located, the majority of technological development takes place in Western countries. However, since the developing countries suffer food insecurity the most, this lack of investment is an important hindrance to the development of the insects as food and insects as feed industry.

Entrepreneurs in the insects as feed sector see enormous challenges to fit their products into the industrial processes of the livestock and compound feed industry. Farmers, for instance, were described as extremely risk averse and conservative, thus, feed trials are not easily allowed. Another client, the compound feed industry, is a mature industry, which produces feed products which are extremely fine-tuned to fit the needs of the animals. Thus, changing ingredients of the compound feed requires long trial periods and various adjustments (e.g., in regard to the composition and processes). An entrepreneur describes the trials as follows:

> *"When they first started the trials the nutritionists were on this thinking 'I officially remove fish meal and I put insect meal instead'. That's not the good way to do that because if insect meal is close to fish meal it's not the same. It means that there is a process of rethinking feed that has to be made by the nutritionist in the compound feed industry. You need first to balance [the ingredients] and you have to rethink your formulation of feed. This work has started maybe two years ago and is still in process with the nutritionist in animal nutrition industry. It takes time." [Fe11_76]*

The compound feed industry is also a globalized industry reliant on huge quantities with strict protocols and standards. Thus, as farmers and livestock producers, the industry is risk averse. A pioneer in the sector describes the problem the company faces as follows

> *"Total production capacity of the insect space is small and we are taking a large part of it. A lot of products that you see in the market are from us. This doesn't help because the big future contracts that needed to change. If you look at the strategy of the big agriculture companies all of the big feed companies, high-end proteins are in the strategic area of the company risk profile. [...] Therefore, they typically do not accept single source suppliers or risky suppliers. We are at this point an absolute risk if we would supply the biggest feed/ agricultural companies. Simply because there is no other suppler to address this risk and secondly because we are financially weak compared to many other companies. We need to establish larger production base we need to establish internationalization. We are beyond the start-up phase, we are a production company, but we are not a solid international operating company.*

> *So there is another step to take. If the insect industry [wants to become an attractive] industry in the future, it needs reliable food ingredient producers with multiple sources. [Fe1_83]*

The phenomenon described by this company represents a risk to developing a resilient food chain and to produce a system change as other insect producers describe it.

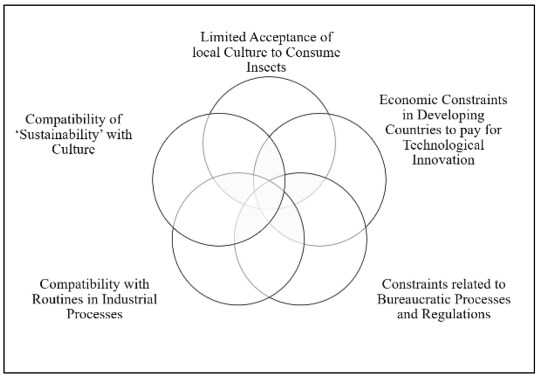

Figure 42: Diffusion Dynamics in the Insect Economy

A factor that influences the adaptation of Insect Economy is whether sustainability is relevant within a culture or not. In countries, where it is relevant, this factor favors the development of the Industry. In those where it is not relevant, other arguments are needed for the Industry to proliferate.

In conclusion, five factors of diffusion dynamics could be identified which are visualized in Figure 42. Those are updated in the Morphology. Furthermore, the term of dimension the dimensions itself is updated to 'factors of diffusion dynamics.' Among the included factors, four represent a potential hindrance to the development of the Insect Economy (1-4) and one presents a potential opportunity (Awareness for Sustainability among the Population). Appendix 11 provides further details on the factors and corresponding interview responses.

4.3.8 RISK FACTORS

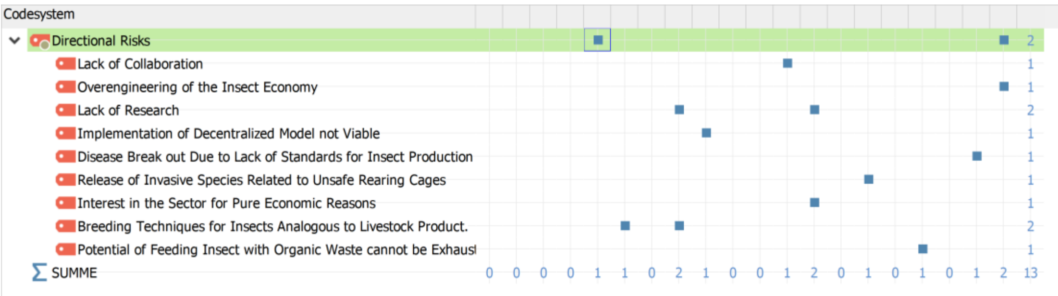

Figure 43: Risk Factors in the Insect Economy

The interview partners made reference to nine risk factors that might hamper the sustainable development of the sector. Figure 43 provides an overview of these risks. While some are common in other industries as well as lack of collaboration, others are more specific to the industry. Those refer to the issue of 'over-engineering', risk that the decentralized model is unfeasible and the risk to repeat breeding patterns from conventional livestock rearing. These risks are addressed in more detail in the following paragraphs.

One interview partner stressed the issue of 'over-engineering the Insect Economy' because in his opinion the players in this sector 'think like waste management engineers.' A relevant example that explains this phenomenon is as follows:

> *"[A large player in the field] just announced a $70 million funding round and they have realized that labor is what's killing them. So they are doing everything robotic. I am very interested to know what their output tonnage is and what their capital cost is. It is going to be more than $2,000 to $3,000 per output ton of capital. [Another pioneer] is producing 7,000 tons of meal for a $15 million to $25 million investments. So that is $3,500 of investment to produce one ton per year does that make sense? So if I buy an acre of land at $2,000 and I can produce more than one ton of soy meal you see then my capex for my soy is cheaper." [W1_32]*

This entrepreneur advocates for a small-scale, low-cost approach because he sees enormous potential in using the efficiency of the black soldier fly, as a very effective waste converter by using it without large technological investment.

Another risk is that the decentralized model - which is hyped among the entrepreneurs - is not viable. At least not yet, as some entrepreneurs mention. The reason is that the technology behind decentralized technologies (e.g., shipping containers) requires a lot of fine-tuning to function smoothly without intensive maintenance. The statements on this concern, however, differed. Other entrepreneurs mentioned that they were already exporting such technologies.

Moreover, there is a risk that ventures enter this field of insects as food or feed solely because of economic reasons. This goes hand in hand with the morally questionable approach to apply breeding techniques for insect rearing analogous to the livestock industry. An entrepreneur applying these techniques made the following comparison:

> *"I always say, 10.000 years ago in Mesopotamia, a pig had 11 ribs, today it has 17. Only through breeding and not through genetic engineering. And so, we will not build breeding lines with traditional breeds that we will later connect with each other. We are already doing a lot and are already getting larger larvae. We may also manage to get another amino acid spectrum or lauric acid for pig nutrition. Our products already contain 48 percent of it and we can certainly influence that. There are other effects that we are exploring through basic research." [Fe7_92-93]*

In conclusion, nine risk factors could be identified. Those are updated in the Morphology.

4.3.9 SUMMARY OF THE DATA SYNTHESIS

During the process of synthetizing and formalizing the data from the interview responses, 8 dimensions related to the 'dimensions for assessing sustainable business opportunities' were analyzed. Those are:

1. Business Model Building Blocks (with a focus on the Value Proposition)
2. Business Model Innovation Grid
3. Sustainable Development Goals
4. Global challenges

5. Sustainability from the Business Case Perspective
6. Sustainable Business Drivers
7. Factors of Diffusion Dynamics.
8. Risk factors

The research scope focused on (1) ‘Insects as Food,’ (2) ‘Insects as Feed,’ (3) ‘Insects as Organic Waste Converters,’ and (4) ‘Insects as Pet Food, Fertilizer, and Raw Material.’ However, the data analysis showed that (1) ‘Insects as Food’ and (2) ‘Insects as Feed’ are particularly attractive to entrepreneurs. Entrepreneurs do not exclusively focus on one sector, but tend to combine their main value propositions related to these sectors (e.g., insects as feed ingredient) with other value propositions such as feeding insects with organic side-streams, whereby insects function as organic waste converters and by selling insect frass as fertilizer or compost. Thus, it can be said that the business model is usually diversified.

Furthermore, the data show that the entrepreneurs tend to be aware – even passionate - about sustainability. This awareness is reflected in the way the entrepreneurs explained the reasons they chose one sector over another (‘Insects as Food’ vs ‘Insects as Feed’). These explanations were principally linked to sustainability issues. It is also reflected in the 13 Sustainable Development Goals and 10 Global Challenges that the entrepreneurs are currently (consciously or unconsciously) tackling. Additionally, the drivers show that sustainability is at the core of the entrepreneurial spirit: 8 drivers out of 24 were directly related to sustainability, to name some of the various indicators.

More than that, the analysis of the quotes demonstrates that at least some entrepreneurs have (sound) sustainability literacy. The literacy and awareness for sustainability is prevalent among entrepreneurs both in the food and in the feed sector (see 4.3.1). Thus, both sectors fit the concept of sustainable entrepreneurship.

As a result of the data analysis, risk factors and diffusion dynamics were also identified that may hamper the sustainable development of the sector. The principal risk is that the industry development around insects is similar to that of conventional industry practices.

The data related to the Business Model Innovation Grid was particularly meaningful. 20 sustainable business model mechanisms were identified indicating that sustainability is directly linked to the business model of the ventures. It therefore forms the starting point for the development of the Typology.

The data synthesis served to empirically test the morphological dimensions and features and check which of them are useful for characterizing the Insect Economy and which are dispensable. The empirical data show that multiple adjustments are required to better fit the morphology to the reality of the Insect Economy. These modifications were applied to the morphology. The updated version of the morphology is provided in the following section.

4.4 UPDATE OF THE MORPHOLOGY OF THE INSECT ECONOMY

During the data synthesis process, the dimensions of the Morphology were reviewed, compared to the interview responses and updated. Table 10 provides an overview of the modifications. It shoes all of the modifications except for one, namely the morphology dimension ‘Planetary Boundaries’. It was already addressed during the data synthesis – in particular the summary.

The reason the concept ‘Planetary Boundaries’ was not addressed before is that associations to it did not resonate during the interviews. This might be due to the fact that the boundaries figure rather on a meso-level and require joint (political) effort to be achieved.[41] Therefore, it is too complex and far off for entrepreneurs to be useful, which is the reason the category was eliminated from the morphology.

Table 10: Modifications of the Morphology based on empirical evidence

Morphology Dimension	Modifications
Insects as	• Feature ‘insects as organic waste converter” is extended to “insects as organic waste converter and fertilizer.”
Planetary Boundaries	• Deleted
Business Model Innovation Grid: Mechanisms for Sustainable Business Model Innovation	• Fully modified

Sustainable Development Goals (SDG)	• Added Features:
	  • SDG 5: Gender Equality
	  • SDG 8: Decent Work and Economic Growth
	  • SDG 10: Reduced Inequality

Global Challenges	• Features ‘Environmental Degradation’ and ‘Biodiversity Loss’ were combined into ‘Environmental Degradation and Biodiversity Loss’ • New feature: Social Inequity • New feature: General Problems related to the Food Value Chain System
Sustainable Business Drivers	• Fully modified
Diffusion Dynamics	• Term of the dimension changed to ‘factors of diffusion dynamics’ • Fully modified
Risk Factors	• Fully modified

In conclusion, seven morphology dimensions were subject to modifications. One dimension was deleted all together. Thus the updated morphology comprises 21 dimensions and 141 features. Thereof, four dimensions and 23 features refer to the overall category *insects*, nine dimensions and 48 features to the overall category *economy*, and eight dimensions and 69 features to the overall category *sustainability*. The modified version is provided in Table 11. The dimensions and features that were subject to changes are framed in purple and grey shaded.

[41] One interviewee mentioned that he used the planetary boundary concept in order to provide sustainability arguments in favor of his business model. Specifically, he stated that “the food system completely passed the planetary boundaries especially when it comes to the nitrogen cycle and this is where insects could have the impact. Insects could be part of the movement for a healthy and good food either directly or indirectly within planetary boundaries” [Fe1_51]. Thus, the entrepreneur used it to explain current problems of the food chain and the potentials insects have from a general point of view.

Table 11: Morphology: Update

Comment: Modifications contain a purple framework and are grey shaded.

	Dimensions	Features														
Insects	**Insect Orders**	Beetles (Coleoptera)	Moths, Butterflies (Lepidoptera)	Fly (Diptera)	Ants, Wasps, Bees (Hymenoptera)	True Bugs (Hemiptera)	Grasshopper, Cricket (Orthoptera)	Others								
Insects	**Ecosystem Services**	Supporting Services	Provisioning Services	Regulating Services	Cultural Services											
Insects	**Rearing Practices**	Controlled Environment	Semi-Cultivation	Captured in the Wild												
Insects	**Applied Research about Insects**	Forensic Entomology	Economic Entomology	Medical Entomology	Applied Entomology	Yellow Biotechnology	Industrial Entomology	General Fields of Research that include Insects	Fields of Specialization	Others						
Economy	**Products of Economic Activity**	Products of Agriculture, Hunting & Related Services	Manufactured Products	Water Supply, Sewage, Waste Mgm. & Remediation Services	Wholesale & Retail Trade Services	Professional, Scientific and Technical Services	Arts Entertainment und Recreation Services	Service of Households and Services produced by households own	Others							
Economy	**Insects as**	Food	Livestock Feed and Pet Food	Provider of diverse bio-based Materials	Organic Waste Converte and Fertilizerr	Natural Enemies and Pollinators	Others									
Economy	**Business Model Building Blocks**	Key Partnerships	Key Activities	Key Resources	Cost Structure	Value Proposition	Customer Relationship	Cannels	Customer Segment	Revenue Streams						
Economy	**Innovation Object**	Product	Processes and Technology	Business Models												
Economy	**Type of Customer**	Producer (B2B)	Final Consumer (B2C)													
Economy	**Geographic Origin of the Business**	Africa	Asia	Oceania	Europe	Middle East	North America	Latin America								
Economy	**Geographic scope**	Local	Regional	National	International											
Economy	**Markets according to degree of Human Development (HDI)**	Low Human Development (Bottom of the Pyramid Markets)	Medium Human Development	(Very) High Human Development												
Economy	**Life Cycle of the Industry**	Embryonic Stage	Introduction Stage	Growth Stage	Maturity Stage	Decline Stage										
Sustainability	**Business Model Innovation Grid: *Sustainable Strategies***	Optimization	Circularity	Substitution with Renewables	Functionality	Stewardship	Slow Consumption	Co-Creation	Social Entrepreneurship							
Sustainability	**Business Model Innovation Grid: *Mechanisms for Sust. Business Model Innovation***	Circular Economy: Zero Waste	Collaborative Approaches: Institutional Entrepreneurship.	Industrial Symbiosis	Frugal Business	Product Longevity	Licensing, Franchising	Localization	Bottom of the Pyramid	Others						
Sustainability	**Sustainable Dev. Goals (2016 – 2030)**	None	SDG 1	SDG 2	SDG 4	SDG 5	SDG 7	SDG 8	SDG 9	SDG 10	SDG 11	SDG 12	SDG 13	SDG 14	SDG 15	Others

(Global) Challenges	Malnutrition & Food Scarcity	Environmental Degradation/ Biodiversity Loss	Waste Production	General Issues related to the Food Value Chain	Social Inequality	Health Issues	Resource Scarcity	Others		
Sustainability from the Business Case Perspective	Business Case - Natural Case	Business Case - Social Case	Triple Bottom Line							
Sustainable Busin. Drivers	Willingness to support local produce	Increasing Consciousness for Sustainability and WTP	Cultural Opening to More Sustainable Lifestyle	Increased awareness & regulation to minimize waste & promote resource recycling	Demand for Fishmeal-free, Sustainable Products	Changing job market: Increased competitiveness for sustainable employers	Investor Awareness for ESG	Increasing Price Competitiveness with Conventional Product	Others	
Factors of Diffusion Dynamics	Limited Acceptance of Local Culture to Consume Insects	Economic Constraints of Dev. Countries to finance tech. Innovation	Constraints related to Bureaucratic Processes and Regulations	Compatibility with Routines of the Livestock Industry/ Compound Feed Industry	Awareness for Sustainability among the Population	Others				
Risk Factors	Lack of Collaboration	Over-engineering of the Insect Economy	Implementation of Decentralized Technology not viable	Disease Break out Due to Lack of Standards for Insect Production	Lack of Research	Release of Invasive Species Related to Unsafe Rearing Cages	Interest in the Sector for Pure Economic Reasons	Breeding Techniques for Insects Analogous to Livestock Production	Potential of Feeding Insect with Organic Waste cannot be Exhausted	Others

4.5 TYPOLOGY OF SUSTAINABLE BUSINESS OPPORTUNITIES IN THE INSECT ECONOMY

The ‘Business Model Innovation Grid’ is a practice-oriented tool, which aims to inspire businesses to reconceive the way they operate and become more future proof (Bocken et al., 2014, Centre for Industrial Sustainability, 2014). It is composed of dimensions, sustainable strategies and mechanisms for sustainable business model innovation. The data synthesis revealed that the dimensions and sustainable strategies are covered by the Insect Economy. Furthermore, 20 out of currently 52 mechanisms could be recognized in the business models of the ventures in the Insect Economy and found in multiple business model building blocks. This finding confirmed the assumption presented in section 2.5.2. that is a useful tool to assess and classify sustainable business opportunities in the Insect Economy (see 4.3.2).

For these reasons, the development of the typology of sustainable business opportunities primarily bases on the BMIG. As described earlier (see page 141), the mechanisms were bundled according to central commonalities. These central commonalities draw on the morphology dimensions ‘Innovation Object’ and ‘Type of Customer.’

The result of this process is four types of sustainable business opportunities. The types are:

Type (1) Insects as Enablers for a *Naturally* more Sustainable Food Products

Type (2) Insects as Enablers for Sustainable Food Production Systems

Type (3) Insects as Enablers for Empowerment of Producers

Type (4) Insects as Enablers for Change in Consumer Behavior

This section is organized as follows: First, the individual types are described. The next step is to add further dimensions originating from the Morphology as further characteristics to the typology. After that the relation among the types and within business models is addressed. Finally, the results are summarized and an overview in tabular form is provided at the end.

4.5.1 *MECHANISMS* BUNDLED INTO TYPES ACCORDING TO MORPHOLOGY DIMENSIONS ‘INNOVATION OBJECT’ AND ‘TYPE OF CUSTOMER’

In this section, the four types and their respective mechanisms for sustainable business model innovation are described and justified. To do so, I proceeded as follows: First I address the morphology dimension with which it shares the central commonalities. Second, I list the mechanisms and provide definitions for it. The definitions usually originate from the Business Model Innovation Grid available online and is referenced (Centre for Industrial Sustainability, 2014). A full list of the mechanisms with their respective definition and related quotes from interview partners is provided in Appendix 9. Third, interview responses are quoted and interpreted. At the end of the description of each mechanism, I provide a summary.

TYPE 1: INSECTS AS ENABLERS FOR A SYSTEM OF *NATURALLY* MORE SUSTAINABLE FOOD PRODUCTS

The principal commonality shared by the mechanism of Type 1 is the 'Innovation Object,' namely insects as 'product'. This type comprises only one mechanism of the Business Model Innovation Grid (BMIG), namely 'Circular Economy: Zero Waste'. This mechanism is natural to insect rearing systems.

The mechanism '*Circular Economy: Zero Waste'* refers to products and business processes designed in a manner that enables waste at the end of the use phase of a product to be used to create new value (Centre for Industrial Sustainability, 2014). It applies to the Insect Economy because insect rearing is by nature a near-to-zero-waste-process. The process outcomes are insects and compost. For instance, company M3 states "*We strive for a zero waste cycle. The larvae can eat through most objects- even through a whole watermelon. They will eat through the whole rind, but that will be left. So if you do not pulp the food waste and treat it like a salsa-like consistency, the larvae cannot break it down more efficiently. So every now and then you have to peal of an avocado etc. that will be shifted out of that process*" [M3_93].

In addition to this natural benefit, there are other intrinsic benefits of using insects, namely:

- The feed conversion efficiency (see page 103) (Paoletti and Dreon, 2005).
- The limited space required for rearing insects and,
- Their fast and productive reproduction cycle (Dossey, 2013).

Interviewee Fe1 puts it as following "*All animals eat insects. We do not give them currently to animals. If we feed them, we see all kinds of benefits: Better taste, more health, longevity, higher productivity, higher efficiency in growth. All those things lead to - in my view the most important - development that everything has to end up in a state where we are within planetary boundaries*" [Fe1_50]. Thus, value propositions consisting of insects as feed and insects as food increase sustainability in the food value chain because insects themselves are naturally healthier and more climate-friendly than conventional protein-based alternatives.

In conclusion, Type 1 refers to the inherent characteristics when using insects as a source of food and feed and is therefore labeled 'Insects as Enablers for a *Naturally* More Sustainable Food Products.' The term "naturally" is highlighted in italics to show that these benefits are bottom-line sustainability effects.

TYPE 2: INSECTS AS ENABLERS FOR SUSTAINABLE FOOD PRODUCTION SYSTEMS

The central commonality of Type 2 is 'Processes and Technology' as 'Innovation objects.' It clusters five mechanisms. In the following list, these mechanisms are defined, and their application in the Insect Economy is explained:

1. *Circular Economy: Modularity*: This mechanism was identified as a new mechanism as a result of the data synthesis. It refers to the fact that companies

aim to standardize their insect production system and build modules that can be assembled anywhere in the world. In that way, the business model is easily replicable and can globally expand. A dominant approach in the context of the Insect Economy is using shipping containers as modules to build rearing and processing facilities for insect farms. Company Fo2 states that it can even produce its insects in the North Pole. "*We have a completely closed system, so the weather does not influence our production*." [Fo2_66]

2. *Reuse, Recycle, Remanufacture*: In the context of the business model grid, these activities refer to reusing produced goods (see page 243 in the Appendix). In the Insect Economy, reuse, recycling and remanufacturing are taken out by retrofitting existing infrastructure to build rearing facilities, e.g., abandoned buildings, farms, and recycle material for construction. A food company stated that "*instead of building new facilities, we are using empty warehouses. We use the cover of the warehouses, and inside we build the climate-controlled rooms. We are not building something new, but we are only using the existing infrastructure*" [Fo2_106]. Another insects-as-food company states "*The construction materials that we try to use are used as well. They are leftover parts. They are also cheaper that way*" [Fo4_34].
3. *Industrial Symbiosis*: is a process-orientated solution turning waste outputs from one process into feedstock for another process or product line (Centre for Industrial Sustainability, 2014). Insects are capable of consuming different organic side streams. An insect-as-food producer, for instance, states that "*We use surplus fruit or "unpretty" fresh fruit which we source from farms, food producers, and grocery stores*" [Fo8, 61]. Moreover, the insects-as-feed producer states "*We are looking into container solutions particularly for food and beverage processors and take their bio-solids - and not their waste. These large food and beverage producers require treating their wastewater, so they are left with large amounts of bio-solids, and that is what we are looking to work with*" [Fe2_92].
4. *Open Innovation:* "The Open Innovation paradigm treats R&D as an open system, and stresses the relevance of coupled processes, linking outside-in and inside-out flows of ideas by working within alliances of complementary companies" (Fichter, 2009; pp. 357). This mechanism does not appear in the data, but the literature review. Open Innovation in the Insect Economy takes place by collaborating with universities and research institutes (e.g., University of Wageningen, VENIK, Insectcentre, Lowe Center), and by forming part of a research project (e.g., ChitoTex, CHITINSECT). For this reason, it is considered in Type 2.
5. *Product Longevity*: refers to product durability and longevity through product redesign, which potentially slows product replacement cycles (Centre for Industrial Sustainability, 2014). This mechanism of sustainable business model innovation was found in a business model of a consumer product producer, which enables consumers to produce their own insects. The founder describes her product as following "*we have designed [our product] so that it is as durable as possible and it is easy to repair. That is to say, it is designed to be modular to a certain extent, and that individual parts can be easily repaired. Otherwise, it would also be logistically difficult for us, because the product also has a certain size. Instead, we can send individual components, which the user himself could exchange."* [Fo7_53]

Both the mechanisms and the corresponding interview responses refer to technology and processes to produce insects as food and feed or to use them as a waste management tool. If business models that use these mechanisms become a widespread solution, they produce environmental benefits complementary to the natural benefits provided by insects. Thus, they can contribute to creating a sustainable food production system. For that reason, this type is labeled 'Insects are Enablers for Sustainable Food Production Systems.'

TYPE 3: INSECTS AS ENABLERS FOR EMPOWERMENT OF PRODUCERS

The central commonality that the mechanisms of Type 3 have, is the 'Type of Customer' producers ('B2B'). Seven business model innovation mechanisms form part of this type. Those are defined and related to the Insect Economy in the form of bullet points:

1. *Bottom of the Pyramid*: refers to people live who with less than 1.90 dollars per day. Thus the intention of the Bottom of the Pyramid-concept is to reduce poverty and inequality of the very poor by giving them access to markets.

    - A company that operates in Africa states "*The business model is as follows: the partner breeds turkeys, chickens, guinea fowls and quail, sold as kits together with a set of feeds [insects] to smallholder farmers. The farmers are buying 20 of these kits. They need two of them for themselves and sell the rest at the roadside. So far, we have reached a thousand of these smallholder farmers. Our goal is to reach 2000 to 5000 farmers.*" [Fe7_44]
    - An Asian start-up founder asks "*Why shouldn't farmers and small-farmers not do it [insect rearing] themselves rather than having their waste being shipped somewhere and then insects are produced and then the insects are sold back to the same farmer at a premium.*" [M1_31]

2. *Empowerment*: This mechanism was identified during the data synthesis. In the context of the Insect Economy, the term refers to improving the market power of underprivileged businesspeople, particularly in wealthy countries to enlarge their choices, reduce inequality and enhance their active participation in society.

    A North American company states that "*what we are doing is we are empowering farmers to make their own feed independent of big farms of soy which is a huge problem and hasn't been done before. We do this by integrating our cities with their farms*" [W1_16]. This company offers a logistic concept which connects food waste producers from cities with small-scale farmers to so that they can achieve *feed autonomy*. This autonomy is achieved by providing the farmers a low cost kit consisting of a small scale insect rearing station and insect larvae and on a regular basis delivering food waste. The larvae feed on the food waste while the farm animals feed on the insect larvae that grows on the waste. The low cost approach can be achieved because the entrepreneur uses a distinct model than that of other entrepreneurs in this field. He states "*So instead of using a factory, the mating system that I'm developing doesn't require a factory but can just be put outdoors and so that drops our capital requirement from $150 a square foot to $25 a square foot.*" [W1_14]

3. *Incubators and Entrepreneur Support Models*: In the Insect Economy, one entrepreneur actively supports other entrepreneurs in building their business – be it by providing advice or by enabling them to replicate an existing business model. Related interview responses for this archetype are:

   - *“in Vietnam, we cooperate with [an insect company]. [The founder] has learned from [us] and has taken over most of the technology. [The company] works on a low technology basis due to lack of funds. [We] have developed bioreactors which, however, have higher costs. [We] help to collect investment funds for [the start-up in Vietnam].”* [Fe7_40]
   - *"I also support some young entrepreneurs who can become my competition. Still, we also have to be a significant industry, and we have pioneering advantages where the margin is bigger. With increasing production, however, automatically the margin goes back. But I am convinced that one must be optimistic”* [Fe7_109].

4. *Producer Education, Communication, and Awareness*: … is a mechanism that was created as a result of the data synthesis. It refers to the strategic approach of entrepreneurs to educate, raise awareness and communicate with their clients about their clients’ impact and opportunities to create positive social and environmental impact. To be successful, entrepreneurs strategically align economic success and sustainable (non-monetary) activities by means of creating a business case for sustainability. A North American entrepreneur explains this approach as following

   > *“Another great example that I use from a marketing perspective is every 20 to 25 liters of food waste that we pick up brings back one dozen eggs, and suddenly that image of [our product] is that it brings back a dozen eggs, versus I educate them. Then I explain that if we were to compost that amount of waste, we would create about 20 cents of compost or $6 a dozen eggs. And so they see that huge shift in valuation between making compost and making food. And so, because of the fact that it has to happen so close to the city, the food waste producers provide nutrients to local farmers. You cannot outsource that; you cannot take that food away and bring it to Ecuador and say I am going to do it here because wages are cheaper in Ecuador.” [W1_74]*

5. *Frugal Business*: refers to easily accessible and inexpensive technology to start insect farming (Centre for Industrial Sustainability, 2014). An example of this approach is as follows: „*we are working with the farmers. They create a house with a roof structure and we put in the equipment. The farmer gets going for $20 to $25 [investment] till they hit production capacity, nobody has to buy the land, nobody has to wait for a permit*.“ [W1_16]

6. *Licensing, Franchising:* Licensing is commonly done by companies that develop insect rearing technology and then license this technology. These approaches apply to multiple ventures in the Insect Economy, e.g., Fe3, Fe7, M3, W1.

All seven mechanisms contribute to improving the market power of low-income producers in both highly and less developed countries. The opportunities emerge when these target groups get access to cost-effective technology to rear insects for food or feed production. In that way, they can secure their livelihood and gain a certain degree of empowerment. The following interview response exemplifies these gains:

> *"In Finland, there are several hundreds of farms that go bankrupt every year, and so they go out poor. […] We have about 150.000 farms in Finland, and they are looking for new businesses right now. They have an empty space, but they do not know what to do with it. So we help them for example to start an edible insects' farm" [Fo3, 63].*

Another example provided by an entrepreneur who operates in a BOP-country is

> *"We have developed a technology that modifies off-the-shelf components to optimize farming yield. This empowers rural farmers in developing countries to raise insects while creating a viable revenue stream." [Fo1_56];* He is convinced that *"You do not necessarily need to give fish to people. You need to teach them how to fish. And that is what our company is trying to do. Farmers can become their own entrepreneurs. They can find ways to supplement their income" [Fo1_63].*

As this type targets producers and provides them market power, it is labeled 'Insects as Enablers for Empowerment of Producers.'

TYPE 4: INSECTS AS ENABLERS FOR CHANGE IN CONSUMER BEHAVIOR

The central commonality of Type 4 is the 'Type of Customer' which – as opposed to type 3 - is final consumers ('B2C'). Two mechanisms were identified that share this commonality. Those are:

1. *Radical Transparency about Societal Impacts:* refers to the attitude of organizations to directly address threats and opportunities related to quality, safety, ethics, and environmental impact of their products (Centre for Industrial Sustainability, 2014). An example of the way this mechanism applies in a venture is as follows: "*we are writing a manifesto where we are committing to things, and through transparency, we show how things currently work and what needs to be improved.*" [Fo5_125]
2. *Consumer Education, Communication and Awareness:* Consumer education models sensitize consumers about the impact of their purchases. It induces consumer activism that is based on the concept of dollar voting (Centre for Industrial Sustainability, 2014). In the example of the Insect Economy, consumer education is a fundamental part to convince consumers about the benefits of eating insects and therefore, make more sustainable purchasing decisions. At the same time, it is an intrinsic part of the business model to gain customers. An entrepreneur states about the sales success of the products: *"I would like to attribute a lot to what we have done in the media: social media advance and all that in past two years"* [Fo4_10].

> However, it is not only about gaining customers, but also about raising awareness about their clients' impact and opportunities to create positive social and environmental impact. An entrepreneur states that "[*our product] is supposed to show that you can feed yourself a bit outside of your habitual food ideals, or a bit outside of the comfort zone, even with insects or whatever*" [Fo7_75].

Both mechanisms aim to raise awareness of final consumers about the (environmental and social) impact of meat consumption and aim to change eating habits. The ventures that use these mechanisms promote insects as food (e.g., insect burgers, protein bars or as a hive where consumer become prosumers and produce their own insects as food). For now, they are only active in markets where significant purchasing power prevails.

Because this type targets final consumers and aims to promote cultural change through awareness raising in the context of promoting insects as food, this type is labeled 'Insects are Enablers for Cultural Change in Consumer Behavior.'

4.5.2 SUMMARY AND OVERVIEW OF THE TYPOLOGY

The grouping of the mechanism of the Business Model Innovation Grid led to identifying four types of business opportunities. The types bundle the mechanisms for sustainable business model innovation according to central commonalities. These central commonalities draw on the morphology dimensions 'Innovation Object' and 'Type of Customer.':

- Type (1) Insects are Enablers for *Naturally* More Sustainable Food Products
- Type (2) Insects are Enablers for Sustainable Food Production Systems
- Type (3) Insects are Enablers for Empowerment of Producers
- Type (4) Insects are Enablers for Cultural Change in Consumer Behavior

It shows that insects can become enablers for more sustainability related to food.

Six out of 20 mechanisms for sustainable business model innovation did not fit one of the four types. The exceptions are (1) 'Move to Renewables,' (2) 'Green Chemistry', (3) 'Product Service Systems,' (4) 'Collaborative Approaches: Institutional Entrepreneurship,' (5) 'Hybrid Businesses & Social Businesses,' and (6) 'Localization'.

The reason for (1) 'Move to Renewables,' and (2) 'Green Chemistry' did not fit is because the typology oriented on insects as enabler for sustainable food. Both mechanisms go beyond this scope. The reason for the 'Hybrid Business' (4) not fitting is that it constitutes the form of corporation and could theoretically fit all of the types.

A Product Service System (3) is considered a mechanism for sustainable business model innovation. However, whether such a system creates benefits for all parties depends on its design. In the following example of a European entrepreneur, it is unclear if it truly creates benefits, in this case for the farmer. He explains: "*We are offering rearing technology to the farmers and then we offer the whole process how to rear insects and then we tell the farmer's how to do that at a high level and then we buy all that from the farmers and sell it to the food companies. So if you want to start* *farming, we can offer you everything that you need for that." [Fo3_61]*. Thus, further analysis is required to categorize this solution as sustainable.

The reason for the 'Localization' not fitting is that it could fit both Type 2 and Type 3. Localization refers to the practice of embedding a business near its consumer market, sourcing the resources locally and adjusting the products and services to local needs (Centre for Industrial Sustainability, 2014). This characteristic produces the opportunity to both enable sustainable food production systems and empower producers. In regard to the latter, localization can produce social benefits because it can create job opportunities and therefore, generate income for potentially deprived people. In regard to enabling sustainable food production systems, some entrepreneurs believe that "*the model for insects [is] a decentralized infrastructure*" [W1_16]. Decentralization can introduce wide-spread innovation as an Asian feed producer mentioned: "*The idea [to produce insects-as-feed] is opposite of what is the fishmeal and soybean market today. Fish and soybean are commodities which are produced at the other side of the world and travel on the cargo container going to Asia from South America, etc. We think that bioconversion allows to produce protein locally and to be used on the local market*" [Fe11, 31]. Finally, it can be mentioned that sourcing feed from nearby farms is considered a significant selling feature to some customers because it is fresher and requires less storage [Fe5_71].

Table 12 shows a synthesized result of Typology of Sustainable Business Opportunities.

Table 12: Typology of Sustainable Business Opportunities in the Insect Economy

Dimensions/ Title	Insects as Enablers for Business Opportunities that Create…			
Label of the Types	**Insects as Enablers for *Naturally* More Sustainable Food Products**	**Insects as Enablers for Sustainable Food Production Systems**	**Insects as Enablers for Empowerment of Producers**	**Insects as Enablers for Cultural Change in Consumer Behavior**
Description	Insects as Food and Feed and Fertilizer	Technology and processes to produce insects or to use them as a waste management tool	Accessible technology and processes for (low-income) producers to rear insects	Awareness raising in the context of promoting insects as food
Central Commonality (Morphology Dim.): Innovation Object	Product	Technology and Process	Mixed	Mixed
Central Commonality (Morphology Dim.): Type of Customer	Mixed	Mixed	Producers (B2B)	Final Consumer (B2C)
Business Model Innovation Grid: **Mechanisms for Sustainable Business Model Innovation**	Circular Economy: Zero Waste	Circular Economy: Modularity	Empowerment	Radical Transparency about Societal Impacts
		Reuse, Recycle, Remanufacture	Bottom of the Pyramid	*Consumer* Education, Communication and Awareness
		Industrial Symbiosis	*Producer* Education, Communication and Awareness	
		Product Longevity	Frugal Business	
		Open Innovation	Incubators and Entrepreneur Support Models	
			Licensing, Franchising	

CHAPTER 5: CONCLUSION

This research project aimed to explore, describe and characterize business opportunities related to insects as biological resources (research question 1: Chapter 3) and assess and classify their potential to foster sustainable development (research question 2: Chapter 4). The theoretical fundament of this project consisted of sustainable entrepreneurship, particularly related to business opportunities, and of sustainable innovation and sustainable business models. This chapter reflects on the overall contribution of this project, both related to each of the related scientific fields and practice. It further addresses the limitations as well as the potential for future research that the Insect Economy enables.

5.1 SCIENTIFIC CONTRIBUTION

The Insect Economy and particularly, sustainable ventures related to insect-based food production systems provide a rich context of research in the academic fields of sustainable entrepreneurship, sustainable innovation, and sustainable business models. In the following subsections, the main contributions of this research to each of these academic fields are addressed and set in the context of current research advances in these areas.

5.1.1 SUSTAINABLE ENTREPRENEURSHIP

Fichter and Tiemann (2018) define sustainable entrepreneurship "as the discovery, creation, evaluation, and exploitation of opportunities to create innovative goods and services that are consistent with Sustainable Development Goals." Based on this definition, this research contributed to sustainable entrepreneurship in three ways: First, it introduces the concept(s) '(Sustainable) Bio-Economy.' Second, it develops the concept 'Insect Economy' – and particularly, the developing regime related to insects as food and feed - as contexts for creating innovative goods and services that are consistent with Sustainable Development Goals. Third, it provides a set of dimensions to assess sustainable business opportunities. All three aspects are addressed in further detail in the following paragraphs.

INTRODUCTION OF THE POLICY CONCEPT '(SUSTAINABLE) BIO-ECONOMY' AND THE TERM 'INSECT ECONOMY' TO SUSTAINABLE ENTREPRENEURSHIP RESEARCH

This research focused on business opportunities with the overall objective to identify opportunities that hold the potential to foster sustainable development. In this pursuit, this research project introduced three interrelated research contexts to sustainable entrepreneurship research: 1st the Bio-Economy, 2nd the Sustainable Bio-Economy and 3rd the Insect Economy (see Figure 44):

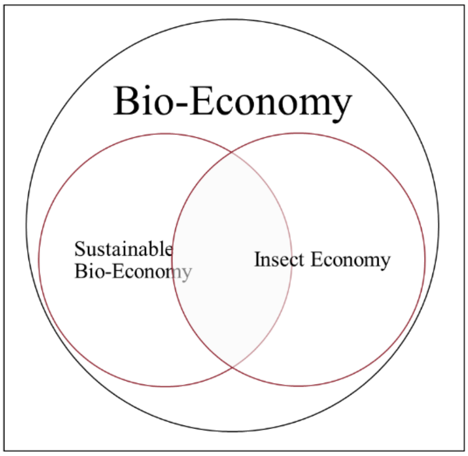

Figure 44: Concepts for Sustainability as Context for Sustainable Entrepreneurship Research.

1. The Bio-Economy was identified as a policy concept that provides a fruitful context to enable business opportunities for sustainable development (2.3).
2. As the Bio-Economy risks limiting its sustainability efforts to eco-efficiency and eco-effectiveness, this research follows the quest for a *Sustainable* Bio-Economy as pronounced by the International Advisory Committee of the Bio-Economy. It defines a Sustainable Bio-Economy as a Bio-Economy which solves global challenges by enabling the progress of decoupling economic development from natural resource use and sustainability of its footprint (page 31). To reach a Sustainable Bio-Economy, it is fundamental that business opportunities have embedded a social and a natural case, in addition to a business case (see 2.3.5).
3. Implanted in the Bio-Economy context, the term Insect Economy was developed. It is defined as a subset of innovative and sustainable products, processes, and services resulting from the Bio-Economy which bases on the use of insects as biological resources (page 57).

The Bio-Economy served as a framework to identify business opportunities based on insects. Research chapter 3, which explored, described and characterized the Insect Economy builds the foundations to confirm that this context provides many ideas for sustainable entrepreneurship research because:

- Insect-based solutions can be found in 7 classes of products of economic activity (CPA) and 25 subcategories (see Figure 26)
- It holds a broad spectrum of sustainability-related characteristics such as potential to (1) contribute to 13 out of 17 Sustainable Development Goals, and (2) to tackle ten global challenges, and (3) it is fueled by 24 business drivers whereof eight of these 24 are directly related to sustainability (see Table 11: Morphology: Update).

In the process of (assessing and) classifying business opportunities in the Insect Economy, it could be shown that the Insect Economy holds the potential to contribute towards a transformation to a Sustainable Bio-Economy. Indications for this transformation became apparent (1) by clustering the business models into types (see 4.5.1) and (2) by bundling the identified types ((1)- (4)) into higher-level categories.

The clustering into types showed that business opportunities based on insects hold the potential to enable a system of naturally more sustainable food products (Type 1), enable a sustainable food production system (Type 2), empower producers (Type 3), and change consumer behavior (Type 4). These innovations have the potential to bring about disruption because entrepreneurs are making efforts to change current legislation (see Collaborative Approaches: Institutional Entrepreneurship). Furthermore, the analysis showed that most entrepreneurs have mental models that are tuned for sustainability (see 4.3.1). If, however, these mental models are to be predominant and produce desired outcomes, they require further in-depth analysis.

All in all, it could be shown that entrepreneurs in the Insect Economy are promoting market transformations through (1) innovative products, process and business models and (2) by actively influencing legislation, creating new patents and industry norms as well as (3) by educating consumers and priming them for market adoption (Pacheco et al., 2010). Thus the Bio-Economy, the Sustainable Bio-Economy, and the Insect Economy provide a fruitful context for sustainable entrepreneurship research.

RELEVANCE OF THE 'DIMENSIONS FOR ASSESSING SUSTAINABLE BUSINESS OPPORTUNITIES' FOR SUSTAINABLE ENTREPRENEURSHIP RESEARCH

The aspect of business opportunities held a key role in answering the research question 2, namely to assess and classify sustainable business opportunities. In the context of this work, sustainable business opportunities are defined as situations in which new goods, services, raw materials, business models and organizing methods can be introduced and sold at greater than their cost of production and which are consistent with the Sustainable Development Goals (page 35). Based on this definition, the 'Dimension for Assessing Sustainable Business Opportunities' (see Table 8) was developed.

These dimensions are: (1) Business Model Building Blocks, (2) Business Model Innovation Grid, (3) Sustainable Development Goals, (4) Global challenges, (5) Sustainability from the Business Case Perspective, (6) Sustainable Business Drivers, (7) Factors of Diffusion Dynamics, and (8) Risk factors. They were empirically tested during data synthesis and used to classify business opportunities in the Insect Economy.

Dimension (1) – (3) are based on formal frameworks. These allow for a structured assessment of the research data – which in the present case were obtained from interviews. Notably, the Business Model Innovation Grid (2) proved useful for a detailed analysis of the data and is addressed further in section 5.1.3.

The remaining dimensions provided meaningful insights to gain a broader picture of the assessed data. However, they were too unspecific to be useful for further classification:

- Regarding *global challenges* (4), there exist diverse approaches to assess them. This assessment depends upon others on the priority of the organization that makes the assessment (KPMG vs. United Nations vs. Millennium Project, see 2.1). Thus, finding a suitable framework to assess global challenges requires a preliminary assessment to make it context specific (Morioka et al., 2018).

- Dimension (5), *Sustainability from the Business Case Perspective*, was also not suitable for the data assessment.
- Regarding Sustainable Business Drivers (6) and *risk factors* (8), while some drivers and risk factors are generalizable for multiple sectors across industries (see page 41), others vary according to the specific opportunities and geography.
- For the assessment of the *factors of diffusion dynamics* (7), the analysis drew on key factors identified by (Fichter and Clausen, 2016). However, as the authors state in their article "it is possible only to a limited extent to identify key factors significant across all diffusion cases" and other aspects need to be considered such as diffusion processes of sustainable innovations (Ibid, p. 53).

Table 13: The relevance of the Dimensions for Assessing Sustainable Business Opportunities for future research in Sustainable Entrepreneurship

	Dimensions	*Relevance for future research*
1.	Business Model Building Blocks applied to Morphology dimension 'insects as'	Enables Structured Assessment (and Classification)
2.	Business Model Innovation Grid	Enables Structured Assessment (and Classification)
3.	Sustainable Development Goals	Enables Structured Assessment (and Classification)
4.	Global Challenges	Enables Soft Assessment
5.	Sustainability from the Business Case Perspective	Not Suitable for Data Assessment
6.	Sustainable Business Drivers	Enables Soft Assessment
7.	Diffusion dynamics.	Enables Soft Assessment
8.	Risk factors	Enables Soft Assessment

The classification, which led to the typology development, also drew on other dimensions of the morphology containing all characteristics of the Insect Economy. The morphology includes the dimensions for assessing sustainable business opportunities and 13 other dimensions (see. 4.4). For the classification, one dimension for assessing sustainable business opportunities (mechanism for sustainable business model innovation) and two other dimensions were used. Thus, researchers planning to draw on the dimensions for assessing sustainable business opportunities have to consider variables that go beyond these dimensions to classify research data.

All in all, the empirical test of the set of dimensions shows that they resonated among the interviewed entrepreneurs. This demonstrates that they are relevant for assessing (sustainable) business opportunities. In particular, the business model building blocks (1), the Business Model Innovation Grid (2), and the Sustainable Development Goals (3) allowed for a detailed analysis of the research data. Thus, those dimensions can serve as a point of departure for further research related to business opportunity assessment for the emerging field of sustainable entrepreneurship research (Binder and Belz, 2015). For an overview, see Table 13.

5.1.2 SUSTAINABLE INNOVATION

COMBINING MESO AND MICRO LEVEL ANALYSIS TO STUDY A MULTIDIMENSIONAL OBJECT

This work created the concept 'Insect Economy' and introduced it to sustainable innovation research. It studied this concept from both the meso-level, namely the sectoral level, and the micro-level, namely the business model level. During the analysis, both levels were systematically interwoven.

At the sectoral level, a morphological analysis enabled the qualitative study of the Insect Economy as a multidimensional object. The morphological box summarized the most important dimensions and features of the Insect Economy related to insects, economy, and sustainability. Thus, it reduced the complexity and number of variables to make it tangible and describable.

On the business model level, a typology identified and described four types of sustainable business opportunities by drawing on several (dimensions and) features of the morphology. The types serve as instruments to break the meso-level knowledge down to the business model level, which makes it explicit. By describing the types, they became useful for many different user groups, such as researchers and entrepreneurs.

Both levels co-evolved: On the one hand, knowledge gained at the sectoral level set the fundament for the typology based on the dimensions and features of the morphology. On the other hand, the typology development revealed inconsistencies in the morphology such as imprecision, lack of irrelevant dimensions and/or features. These inconsistencies were then corrected (see 4.4.). As a result of the systematic integration of knowledge, the concept 'Insect Economy' could be described and characterized with more precision.

This methodic and analytical approach of combining two levels can also be applied to other topics in innovation research, which aim to theorize sector-related research objectives. It enables a more precise representation of reality in theoretical constructs. This, in turn, increases the relevancy and applicability of theoretical findings for practitioners.

DIFFUSION DYNAMICS IN THE INSECT ECONOMY

As part of the data analysis, factors of diffusion dynamics in the Insect Economy were assessed. Five principal dynamics could be identified: (1) Limited Acceptance of Local Culture to Consume Insects, (2) Economic Constraints in Developing Countries to Pay for Technological Innovations, (3) Governmental Push and Pull, (4) Compatibility with Routines in Industrial Processes, and (5) Compatibility of 'Sustainability' with Culture. Due to the fact that this work drew on qualitative research methods, the factors of diffusion dynamics identified in this thesis cannot be expected to be complete. Nevertheless, they provide relevant insights into the development of ventures in the Insect Economy.

To better explain the insight, it is necessary to draw on findings from Fichter and Clausen (2016). In their paper, they show that *key factors of diffusion dynamics of sustainable products and service innovations* resonate differently depending on the *group of innovation*. These key factors resulted from a factor analysis of 22 variables that potentially influence the diffusion trajectories of sustainable innovations. The group of innovation resulted from grouping 100 cases of product and service innovation into five groups of innovations. These five are: (1) Efficiency Enhancing investment goods from established suppliers, (2) Comprehensible products of end users, (3) Government-supported investment goods from pioneering suppliers, (4) Radical innovations requiring major behavior modifications, and (5) Complex products with unclear or long-term benefits.

This grouping can also be applied to the case studies used for the assessment of sustainable business opportunities (research question 2). The ones focused on insects as food, feed and waste converters. The value proposition of the business models of each of these focus areas varied between selling insects as resources (food, feed, waste conversion), technology (rearing or waste conversion), and product service system solutions (see 4.3.1 – Value Propositions, page 143).

Table 14: Groups of Innovation and the Insect Economy

Focus Areas	Value Propositions	Efficiency Enhancing Investment Goods	Compre-hensible Products of end Users	Government-Supported Investment Goods	Radical Innovations Requiring Major Behavior Modifications	Complex Products with Unclear or Long-Term Benefits
Insects as feed	Rearing technology				x	
	insects as feed for small holder farmers				x	
	logistics solution				x	
Insects as food	Rearing technology				x	
	Insects as food for End Consumers				x	
	Insects as food ingredients for food producers				x	
	logistics concept				x	
Insects as Organic Waste Converter	Convert different types of waste into biomass				x	

Source: Table based on Fichter and Clausen (2016)

Table 14 shows that the analyzed value propositions correspond in most cases with Group of Innovation no 4, ‘Radical innovations requiring major behavior modifications.’ It is characterized by (Fichter and Clausen, 2016; p. 52):

- Strong need for behavior modifications on the part of users
- Predominantly high degree of innovation
- Obstacles because of strong path dependence
- Good comprehensibility of the innovation

- No self-reinforcing effects yet, in spite of government support

Furthermore, this group can be related to key factors of diffusion dynamics of sustainable innovations. The most noticeable key factors of diffusion dynamics that apply to this group of innovation are (Factor 1) Market power of established suppliers, (Factor 3) Small influence of pioneers, (Factor 5) Compatibility with routines, (Factor 6) Price and cost effectiveness, (Factor 7) Comprehensibility of the innovation. Each factor groups variables influencing the diffusion trajectories of sustainable innovations. The identified factors of diffusion dynamics in the Insect Economy correspond to some of these influencing factors and therefore, to the key factors of diffusion dynamics. The way they correspond to each other is explained in the following paragraphs.

Factor 1: Market power of established suppliers comprises among others the variables ‘size and market power of suppliers,’ and ‘path dependency.’ These variables relate to the identified factor of diffusion dynamic in the Insect Economy ‘Compatibility of routines in industrial processes.’ In the context of the Insect Economy, this factor relates to challenges in the insects as feed area where both feed producers as well as livestock farmers are reluctant with using an alternative feedstock.

Factor 3: Small influence of pioneers: This factor draws on the challenge that “user innovators and small green pioneers usually have significantly fewer resources and power to influence market penetration than established market leaders and big companies. The factor also refers to possible cooperation between pioneering “green” suppliers and user-innovators, who are supported by strong “perceptibility of the innovation” as well as the presence in “media and campaigns.” (Fichter and Clausen, 2016; p. 48). There is no corresponding diffusion dynamic in the Insect Economy. However, the description fits well to the context of the interviewed ventures, which mention that resources are scarce and the power to influence market penetration is low. Furthermore, entrepreneurs in the field of insects as food showed to have a very high media presence (cf. mechanism for sustainable business model innovation: Consumer Education, Communication and Awareness, page 245). Thus, even though this factor was not identified through data analysis, it seems to apply to the reality of ventures in the Insect Economy.

Factor 5: Compatibility with routines: This factors includes variables such as ‘need for behavior modification’ and ‘compatibility’ - the capacity to connect the innovation to existing technical, institutional, and cultural systems. These variables resonate with the factors of diffusion dynamic in the Insect Economy: (1) Limited Acceptance of Local Culture to Consume Insects, and (5) Compatibility of Sustainability’ with Culture, and (4) Compatibility of routines in industrial processes. The latter was already mentioned in Factor 1. However, the need for behavior modification also applies to insects as food because the end consumers need to be open to consuming insects instead of meat. Thus, this factor seems to fit the context of the Insect Economy as well.

Factor 6: Price and cost effectiveness is principally about the extent to which aspects relating to price, costs, or cost-effectiveness support or inhibit adoption of the innovation and partly, also about the imitation of role models and critical mass phenomena. Moreover, in the areas of insects as feed and food, the aspect of price competitiveness is highly relevant. As mentioned earlier, the price pressure is higher in the feed sector. Still, as long as prices are high, insect-based products are only accessible to consumers in the higher price segment. Therefore, this factor also fits the Insect Economy.

Factor 7: Comprehensibility of the innovation primarily refers to extent to which adopters are concerned with uncertainties. Uncertainties are prevalent in both the area of insects as food and feed. There is, for instance, the issue of limited research, e.g. in regard to rearing practices of specific insect species and to health issues such as allergens that are common to all arthropods. These factors are producing uncertainty on the part of the adopters, which restrains market penetration (cf. Finke, 2013, Katz, 2013, Nowak et al., 2016, Van Huis, 2016). Thus, Factor 7 also applies to the Insect Economy.

So far, it could be confirmed that ventures in the area of insects as feed and food correspond to the group of innovation “(4) Radical innovations requiring major behavior modifications.” However, only two key factors were backed with factors of diffusion dynamics in the Insect Economy. At the same time, three out of five factors resonated with the key factors.

Two out of the five factors of diffusion dynamics in the Insect Economy could not be assigned to any of the key factors above. These are (2) Economic Constraints in Developing Countries to Pay for Technological Innovations, and (3) Governmental Push and Pull. The latter, however, fits the key Factor 2: Political push & pull. Factor (2), however, could not be assigned to any of the key factors neither to any of the variables underlying the key factors.

This factor relates to the support system, such as investors who support the development of the industry to overcome the Death Valley of innovation. The reason for it to not be considered among the factors from Fichter and Clausen (2016) may be because they can explain 62.9% of the variance in the field and were therefore, out of focus. The fact that they emerged in this analysis suggests that the definition of the factors may be reconsidered. For example, Factor 6: Price and cost effectiveness may be extended to (investor) support systems. Another alternative would be to create a separate group addressing the aspect of support systems.

Table 15: Key Factors of Diffusion Dynamics and their fit to the Insect Economy

	Factor 1: Market power of established suppliers	Factor 2: Political push & pull	Factor 3: Small influence of pioneers	Factor 4: Incentive to buy	Factor 5: Compatibility with routines	Factor 6: Price and cost effective-ness	Factor 7: Comprehen-sibility of the innovation	New Factor 8: Support Systems
Limited Acceptance of local culture to consume insects					X			
Economic constraints of developing countries to pay for technological innovation								X
Government push and pull		X						
Compatibility of routines in industrial processes	X				X			
Compatibility of Sustainability in Culture					X			
Result of Analysis (Newly incorporated: cell is higlighed in dark grey)	X	X	X		X	X	X	X

Key Factors of Diffusion Dynamics related to
‚Radical innovations requiring major behavior modifications ,

Source: Table based on Fichter and Clausen (2016)

All in all, it can be concluded, that ventures related to insects as food and feed can be clustered as 'Radical innovations requiring major behavior modifications.' By analyzing the fit of the key factors of diffusion dynamics related to this innovation group to the identified diffusion dynamics in the Insect Economy, the relevant factors for ventures in the Insect Economy could further be complemented (see Table 15). The key factors related to Radical Innovation requiring major behavior modifications, however, did not cover all identified diffusion dynamics related in the Insect Economy. For that reason, the key factor 'Governmental Push & Pull' was added, and a new key factor was created namely, Factor 8: Support Systems.

5.1.3 SUSTAINABLE BUSINESS MODELS

A business model is seen as a vehicle for innovation and as a means to transforming markets. It has become a tool that serves multiple purposes (Geissdörfer et al., 2017) such as systemic analysis, planning, implementation of an organizational system. Business models have also become an innovation object in order to increase organizational performance and competitive advantage. In this thesis, business models were viewed as an innovation object and together with the Model Innovation Grid were used to assess realized business opportunities regarding their sustainability quality.

The Business Model Innovation Grid refers to an online tool based on the Business Model Archetypes introduced in the seminal article of Bocken et al. (2014).[42] It provides a large variety of mechanisms for sustainable business model innovation and related case studies, which are bundled into eight 'sustainable strategies' or archetypes. The archetypes, however, still lack empirical primary data sources, since they were developed from academic and grey literature (Bocken et al., 2014, Evans et al., 2017). Yip and Bocken (2018) addressed this gap by assessing sustainable business model archetypes for the banking industry. This thesis addressed the gap by laying a sectoral focus on the food production system related to insects. The findings are as follows:

First, the archetypes were validated to assess and classify the Insect Economy. Seven out of eight archetypes could directly be identified. Bocken's sustainable strategies bundle 52 mechanisms for sustainable business model innovation. 17 out of 52 mechanisms were recognized in the 20 analyzed business models.

Second, during the validation, shortcomings were identified regarding the mechanisms for sustainable business model innovation. Third, in three occasions where the mechanisms lacked fit to the context of the Insect Economy new mechanisms were created. Those are termed (1) Empowerment, (2) Circular Economy: Modularity and (3) Producer education, communication & awareness. These mechanisms were described and characterized.

5.1.4 CONCLUSION: SCIENTIFIC CONTRIBUTION

The reflection about the scientific contributions shows that this research contributed to research in the fields of sustainable entrepreneurship, sustainable innovation and sustainable business models in multiple ways. It could be demonstrated at large that the Insect Economy provides a rich context for research for the fields above. Furthermore, dimensions for assessing sustainable business opportunities were introduced, tested and synthesized. The combination of doing research at a meso- and micro-level was found to be useful to reflect practical contexts in theory as accurately as possible. Finally, the Business Model Archetypes - here referred to as Business Model Innovation Grid - were found to be relevant and applicable to the context of the Insect Economy and enabled a fine-grained assessment regarding the sustainability of the ventures.

5.2 IMPLICATIONS FOR ENTREPRENEURS

Three practical implications of this thesis shall be addressed in detail. These are: (1) identifying sources of inspiration to identify business opportunities (2) establishing a definition of the term 'sustainability' in the context of the Insect Economy, and (3) linking sustainability to business strategy.

[42] The Business Model Innovation Grid was introduced in section … Business Model Innovation Grid. Here I justify the use of the terminology of the online tool for data synthesis.

5.2.1 SOURCE OF INSPIRATION FOR BUSINESS OPPORTUNITIES

Chapter 3 provides broad information about business opportunities related to insects which entrepreneurs may view as sources of inspiration:

1. The first source can be found in section 3.3 - The Relation of Insects to Nature and Culture - and 3.4 - The Scientific Knowledge about Insects. Those sections may tune entrepreneurs to identify business opportunities.
2. The second source is provided when specific business opportunities from diverse industry sectors are described (see 3.5).
3. The third source is the morphology of the Insect Economy. Being a configuration of an extensive set of characteristics, it may motivate entrepreneurs to configure their own business solutions.
4. The fourth source is the Typology of Sustainable Business Opportunities which shows the way a business model may be configured by using mechanisms for sustainable business model innovation.

These four sources of inspiration can also help entrepreneurs make their ideas more concrete. While the first source is very generic and the entrepreneurs need to be creative to view opportunities, the second one is specific and draws on concrete solutions. The morphology takes an abstract approach to recognizing business opportunities and configuring a solution. The last source, the typology, may help from conceptual phase of the innovation process onwards.

5.2.2 DEFINING THE TERM ‘SUSTAINABILITY’ AND IDENTIFYING SUSTAINABILITY FRAMEWORKS FOR THE INSECT ECONOMY

During the interviews, it became evident that for some entrepreneurs there is a gap between their willingness to become socially and environmentally responsible and the knowledge, skills, and solutions necessary to allow them to integrate sustainability into their business practices. This thesis presents a number of approaches to overcome this bottleneck.

Entrepreneurs may gain a first impression about what sustainability is by reading the first two sections of chapter 2. Section 2.1, namely the dimensions and root causes of global challenges, is relevant because many companies communicate their contribution to solving global challenges to their stakeholders.

Section 2.2 relates to sustainable development and addresses the Sustainable Development Goals (SDG). This concept offers a way of transcending the conflict between economic imperatives and social and environmental goals, as was shown during the data synthesis (4.3.3). The new SDG are designed in a way that they can act as a catalyst in the process of changed attitudes and behavior by providing concrete goals and solution approaches. The SDGs are included in the morphology of the Insect Economy. Apart from that, more and more tools are emerging that directly link business and the SDGs, such as the Institute for Managing Sustainability (2017).

Furthermore, the sustainability guiding principles can serve as a compass for sustainability (see 2.5.4; Breuer et al., 2018). These principles are (1B) sustainability-orientation, (2B) extended value creation, (3B) systemic thinking, (4B) stakeholder integration, (5B) context sensitivity, and (6B) reflecting impacts and outcomes. Morioka et al. (2018) further condense these principles to (1M) economic, environmental and social goals; (2M) adopting a multi-stakeholder perspective and (3M) a long-term outlook. Using these principles can help develop a firm strategy and internal and external communication.

Apart from the theory-based approaches above, the morphology of the Insect Economy can be useful to overcome the bottleneck. It contains eight dimensions and 70 features related to sustainability. As the morphology is set in the context of entrepreneurship and innovation and was specifically developed to characterize the Insect Economy, it can serve as an orientation for sustainable business practice.

5.2.3 STRATEGIC ORIENTATION OF BUSINESS DEVELOPMENT

The definition of sustainability in the context of the Insect Economy is and the existing frameworks for sustainability– as was described above - provide a solid basis for developing a coherent business strategy. This work, however, also set emphasis on the fact that the baseline for anchoring sustainability to the core business is to identify a business case (for sustainability) and business drivers to build a stable business (see again 2.4.5). During data synthesis, relevant business drivers for entrepreneurs in the field of insects as food and feed were identified (see also Appendix 10).

Furthermore, this thesis made reference to the Business Model Canvas which has developed into a major framework for practitioners to develop a business model (Osterwalder and Pigneur, 2010). More than that, it made reference to the Sustainable Business Model Canvas. This sustainable version which was developed by Fichter and Tiemann (2015) is supported by an extensive questionnaire with questions relating to each of the building blocks to check whether sustainability aspects are anchored in every one of it. Thereby, this version of the canvas helps distinguish sustainable from conventional business models.

Another concrete approach to strategic sustainability is using the Business Model Innovation Grid (bookmark). This practice-oriented online tool serves to align the economic argument or customer value and sustainability argument. The grid was subject to in-depth analysis during data synthesis (4.3.2) and was a central element to develop the typology. Particularly, entrepreneurs in the field of insects as food and feed can be inspired both by the typology itself and by the detailed tables containing interview responses (see Appendix 9) can serve as a benchmark or as inspiration for businesses to reconceive their business model with sustainability.

Systematically integrating sustainability into the core business is at the same time a means to communicate company sustainability efforts consistently. Such a consistent approach creates multiple advantages: (1) It increases the impact on solving (global) problems; (2) it can build a reputation with customers, investors and other stakeholders, and it is useful (3) for opportunity discovery. (Browne, 2016)

5.2.4 CONCLUSION

The implications for entrepreneurs showed the way this thesis can be seen as a source of inspiration to identify business opportunities, what sustainability in the context of the Insect Economy means and the ways sustainability can be strategically aligned with economic arguments of the business. It highlighted that the purpose of the company is the litmus test of sustainability in business and that contributing to sustainability does not need to be a philanthropic ambition business, but societal goals and business goals can be tied together. It further referred to specific tools companies can use to align sustainability and business strategically.

5.3 LIMITATIONS

For the development of the typology, a focus was set on insects as food, feed, and waste conversion. The overall characteristics of the Insect Economy, however, clearly showed that the wealth of opportunities to develop sustainable solutions go well beyond these functions. Thus, it can be expected that expanding the research scope to other fields can bring about relevant data for sustainable innovation research.

Another limitation is the restricted number of interviewed entrepreneurs. The analysis of their responses has shown that the configurations of their business models, and particularly the use of mechanisms for sustainable business model innovation, are very diverse. Thus, it can be anticipated that increasing the number interview partners would bring to light further combinations. A more extensive set of combinations can also help assess the combinations that contribute to more sustainability. Answering this question, however, requires a distinct research approach.

Furthermore, this study was taken out as exploratory research. The central limitation of this methodological approach is that it lacks randomized representativeness. These limitations can be overcome by further research, using different methodological techniques to test the validity of these results.

Moreover, the research shows a static picture of the business models and does not open discussion on the ways it can or should evolve over time. It depicts the opportunities for sustainability that these business models can enable, but does not explicitly provide a detailed evolutionary guideline for organizations.

5.4 FUTURE RESEARCH

Earlier in this chapter, a number of reasons were provided about why the Insect Economy, and particularly sustainable ventures related to insect-based food production systems, offers a relevant *context* for sustainable innovation, sustainable entrepreneurship, and business model research. The overall advantage of using this context is that it consists of a broad set of commonalities that the ventures share such as the industry sectors, biological resource (insect), and support system. This allows for comparability and conducting quantitative and long-term studies, which all of these emerging fields of research are lacking.

Researchers who are interested in using this context can draw on the 'Entomology Company Database' (Taponen, 2017). This database is a periodically updated spreadsheet, which consists of an extensive list of companies in the field of insects as feed, food, waste conversion, and biological pest control, and is, therefore, an ideal source to study insect-based food production systems. Thus, other than the support database created for this research which comprises all kind of opportunities related to insects, Taponens' database is limited to four business sectors. Consequently, the Entomology database was only used to a limited extent in this work (see Figure 30). Taponen created the database in January 2016, and only two years later, version 69 already figures 400 companies.

In the following subsection, potential future research topics for each field of research are addressed.

5.4.1 SUSTAINABLE ENTREPRENEURSHIP

Sustainable entrepreneurship research is usually studied in the form of case studies (Cohen et al., 2008, Hörisch, 2016). Using the Insect Economy as a context, opens up a wide field enabling longitudinal studies as well as the quantitative studies. Both methods are underrepresented in this field of research.

To date, there persists reasonable doubt about how and why sustainable ventures emerge. Morioka et al. (2017) propose the hypothesis that they are an emerging paradigm on how to manage efficient businesses in any sector to add positive value to the globe rather than it being an explicit process by companies to directly address a specific social and/or environmental problem. The latter hypothesis is supported by Rauter et al. (2017) who investigated sustainable ventures to better understand their operations and drive towards development. They found that only half of the companies of the sample were founded with the intention of complying with sustainability principles. Furthermore, they found that business models incorporating aspects of sustainability do not differ substantially from traditional business models.

The hypothesis from Morioka et al. (2017) and the findings from Rauter et al. (2017) also seem to hold true for the ventures in the Insect Economy. The reason is that conversations with some entrepreneurs leave reasonable doubt whether the sustainability characteristics of the business model are the result of the systematic focus on sustainability (Stubbs, 2017, Long et al., 2018) or the ad hoc result of the venturing process (cf. Evans et al., 2017). Due to this lack of understanding about the way sustainable ventures come into being, future research should answer the question about the ways sustainable ventures are different from traditional companies, the ways they come to life and how they operate. The Insect Economy can serve as a suitable context for such a research project.

Business opportunities in the Insect Economy with focus on insects as food, feed, and waste converters are in an emerging stage. The business models are still diverse and show multiple characteristics of sustainability as the four types of the typology show (4.5). Follow-up research may analyze the ways contextual factors support and constrain sustainable entrepreneurial activities in the Insect Economy. Such contextual factors might refer to specific legal, institutional and regulatory frameworks, as well as historical, cultural and socio-economic factors (Volkman et al., forthcoming).

Furthermore, future research may examine how sustainable entrepreneurs balance the persistent and conflicting duality between entrepreneurial and sustainability orientation in their decision making (Schick et al., 2002, DiVito and Bohnsack, 2017). For instance, Schick et al. (2002) found that, apart from financial resources, time waste is the most critical obstacle to making more progress towards sustainable business practice. Moreover, Belz and Binder (2015) identified that while finding a double bottom line solution is in many business models still straightforward, this is usually not the case for triple bottom line solutions. Thus, sustainable entrepreneurs need to assume extra effort, e.g., by assuming private costs (at least for a certain period of time) and communicating their tripartite advantages to the consumer.

5.4.2 SUSTAINABLE INNOVATION

The Insect Economy was identified as a fruitful context for sustainability transition research which studies among others innovation paths and diffusion dynamics of innovations. Innovation paths can be understood as “the chain of events of a particular innovation project over time and its embedding in a specific innovation system (individual, organization, network of innovators)” (Clausen and Fichter, 2016; p. 3). And, diffusion dynamics refer to the process of adaptation and imitation of innovations after the first successful implementation or after market introduction (Fichter and Clausen, 2016; p. 4). Both aspects will determine the future development of innovations in the Insect Economy. In-depth study about innovation paths and diffusion dynamics of specific innovation projects will serve to identify and influence their potential ‘sustainable futures.’ (Markard et al., 2012, Clausen et al., 2017)

Innovations are embedded in innovation systems, namely the culture, structure, and practices that an innovation project is related to. Hence, these dominant systems influence the options an innovation project has to prosper. Therefore, understanding this system can help obtain a realistic view of the transformation process in the different socio-technical systems. This thesis proposes to further investigate insect-based solutions related to the food production system due to its intriguing potential for sustainable innovation. Studying the innovation paths of this system “enables us to identify winners and losers (there is no field of transformation with win-win situations only) and makes it easier to develop a policy integrating as many actors and groups as possible in the transformation project and to plan for those negatively affected.” (Clausen et al., 2017; p. 131).

Once innovation is successfully introduced into the market, the process of adaptation and imitation begins. This process is highly intertwined with user practices and lifestyles, complementary technologies, business models, value chains, organizational structures, regulations, institutional structures, and political structures (Markard et al., 2012). These material and immaterial structures influence the diffusion of new thoughts, technologies and practices promoting sustainability in the society. In the case of the Insect Economy, preliminary results have shown that significant obstacles are the compatibility with industrial routines when introducing insects as food or feed as well as legal hurdles related to import and export, and food regulations (see Table 24). Thus, understanding and anticipating the hurdles is decisive to enhance the widespread of insect-based solutions.

Successful innovation projects also require reliable support systems (Fichter et al., 2016). They include agents of change such as political actors, as well as regulatory and institutional frameworks. Support systems differ depending on the socio-technical regimes (e.g., food system), the geographical focus (e.g., national boundaries) or specific institutional contexts. Therefore, a clear regional and thematic scope needs to be defined.

Concerning the system related to insects as food, feed and waste conversion in the European Union, numerous change agents are supporting the ongoing innovation processes. However, the system as a whole is widely fragmented. To foster the system innovations that result from these multiple product and process innovations, it is necessary to evaluate the discrepancies between the current support systems related to insects as food and feed and identify the requirements of adapted systems to stimulate and support it.

Future studies about path dependencies, diffusion dynamics and support systems of the individual socio-technical systems in the Insect Economy, can build on initial research results obtained in the framework of this thesis. These data relate to drivers (4.3.5), diffusion dynamics (4.3.7) and risk factors (4.3.8) and are obtained through interviews with entrepreneurs. However, as explained, future research will have to go beyond this micro-level perspective and adopt systemic views at landscape and regime level to study the transformation processes of the socio-technical systems in the Insect Economy. (Schlaile et al., 2017)

5.4.3 SUSTAINABLE BUSINESS MODELS

Sustainable business models are characterized by a holistic, multidimensional approach to integrate sustainability. For example, Breuer et al. (2018) identified four guiding principles and other four process-related criteria as central for sustainable business models, and Morioka et al. (2017) refer to three business levels on which sustainability should be anchored. These three levels are the *normative* level, which refers to values, attitudes, beliefs, and judgment as a basis for management, the *strategic* level, which refers to reflecting on long-term goals and product-market combinations and the *operational* level, which refers to translating strategic goals into corporate activities. In this research project, strong sustainability characteristics in insect-based business models were found. However, those indicators by themselves are no guarantee that the venture is systematically sustainable. Therefore, further analysis should shed light on the nature of the approach of sustainability in these business models (Morioka et al., 2017, Breuer et al., 2018, Morioka et al., 2018).

Furthermore, research advances on the sustainability frameworks used in this thesis, frameworks, namely the Business Model Innovation Grid, and the Sustainable Development Goals (SDG), would also be helpful to strengthen the link between theory and practice of business and sustainable development in the future. As follows, more specific research aspects for future studies are addressed:

1. Future research could keep exploring and testing sustainable mechanisms in the BMIG and further expand the repertoire of the grid (Evans et al., 2017)
2. Moreover, it can also be dedicated to further investigate the eight mechanisms in the BMIG that dominate in the business models of the venture. The study may

examine the attributes of these mechanisms to gain a deeper understanding of the way they contribute to creating competitive advantage.

3. Future studies may follow the approach of this research in that they also address the contribution of the business models to the SDGs and analyze the interrelation between the mechanisms and their role in contributing to the SDGs.
4. The connection between SDGs and sustainable business models will have to gain in relevance if the SDGs are to be achieved by 2030. A current call for papers about “Business Strategy and Development: Special Issue on Sustainability and the role of SDGs for progressing sustainability” (Skjerven et al., 2017) is pushing this research stream. It asks, for example, how SDGs can be explicitly integrated into innovation processes.

5.5 FINAL CONCLUSION

This thesis introduced the term ‘Insect Economy,’ described and characterized business opportunities in this context, and assessed in detail sustainable business opportunities in the form of realized business models. In so doing, it presented a context in which the role of companies to transform markets becomes most evident. Particularly the innovative business models in the food production system display vivid examples of the ways the entrepreneurs are influencing laws, regulations, and standards and are thereby shaping their market environment.

Insects as biological resources were the focal element of this work. The literature review about the relation of insects to nature and culture unveiled the environmental values held by the insects. They can be seen as connector elements forming a decisive link between the living and the non-living environment. This research has shown that they can also form this link between business and the environment.

It is a significant contribution that this work puts insects into the center stage of this thesis. The reason is that the world is currently experiencing a great wave of disappearing insect species. At the same time, due to the lack of research, it is widely unknown the level of biomass and the number of species disappearing and with them valuable ecosystem services (see again 3.3.3). The business opportunities in the Insect Economy may present a way to overcome this dilemma.

Once insects become part of business activities, their value becomes more visible and, ideally, this will lead to more (positive) awareness about insects (Stuart et al., 2010). In fact, recent news reports about the ability of waxworms to degrade polyethylene (Yang et al., 2014), raised curiosity and served as a subject for small-talk. Additionally, the idea of eating insects is a widely discussed subject in the news. Since 2018, they are allowed to be consumed as food in the European Union (Novel Food Law). Both examples indicate that we are heading in the right direction.

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APPENDIX

Appendix 1 INSECT-BASED COMPANIES FOR MORPHOLOGY DEVELOPMENT

Table 16: Insect-based Companies for Morphology Development

No	*Date of Access*	*Company Name*
1	14.10.2016	4Ento
2	19.10.2016	Agate Bioservices
3	2015.05.21	AgriProtein
4	2016.01.12	Albfertil Naturdünger GmbH
5	02.11.2016	All things Bugs
6	13.01.2017	Amusca (2 Mal kontatiert / LinkedIn und Email)
7	21.11.2016	Anteater
8	2015.05.19	Aspire Food Group
9	28.10.2016	Benzon Research
10	13.01.2017	Beta Hatch
11	2016.01.14	Big Cricket Farm
12	18.10.2016	Bio Best Group
13	19.08.2016	BioBee/ Bio Fly
14	13.10.2016	Biodone
15	2016.01.26	Bioflytech
16	19.08.2016	Biteback
17	14.12.2016	BugBreak
18	14.10.2016	Bugfoundation
19	29.08.2016	Bugs International
20	2016.01.25	Bugsolutely, Thai limited company
21	28.08.2016	Carzu Masu - cheese (random company)
22	2015.06.25	Chapul
23	21.11.2016	Coalo Valley Farms
24	29.08.2016	Ditschke Insekten
25	13.11.2015	Eco Insect Farming
26	15.07.2016	Eco Insect Farming Thailand (EIF Thailand)
27	18.10.2016	Edible Bug Farm
28	19.04.2016	Edible Inc.

29	18.10.2016	Edible Unique
30	2015.05.20	Enterra Feed Corporation
31	15.05.2016	Entobel
32	11.02.2016	Entocube
33	13.10.2016	Entocycle
34	11.02.2016	Entofood
35	2015.06.25	Entologics Nutrientes Sustentáveis Ltda.
36	15.05.2016	Entomo Farms (not EntomoFarms)
37	31.08.2016	Entomofarms (not Entomo Farms)
38	14.10.2016	Entomotech
39	18.08.2016	Entopro
40	2016.01.15	Enviroflight// intrexon llc
41	18.11.2016	Essento
42	2015.06.22	Eucodis Bioscience (specifically ChitoTex EU project)
43	08.07.2016	Exo
44	11.02.2016	Farm 432
45	18.08.2016	FeedTest
46	18.08.2016	Flying Spark
47	18.08.2016	Global Bugs Asia
48	31.08.2016	Grub
49	13.10.2016	Grubby Farms
50	02.11.2016	HaoCheng Mealworm. Inc
51	2016.01.12	Hargol FoodTech (Steak TzarTzar)
52	29.08.2016	Hatch Beta
53	31.08.2016	Heimdal Entofarms
54	2015.05.21	Hermetia (früher Fa. Katz Biotech AG)
55	26.10.2016	HiProMine
56	2015.05.20	Insect Europe BV
57	01.04.2016	Insectitos
58	29.08.2016	Insectubator/ Swarm Protein
59	29.08.2016	Iowa Cricket Farmer
60	05.05.2017	Khepri Biosciences (not in database)
61	2015.05.26	Koppert Biological Systems
62	2016.,01.15	Kreca Ento-Feed BV
63	19,08,2016	Kulisha
64	03.03.2016	Litlle Herds

65	11.02.2016	Livin Farms
66	19.08.2016	Micronutris
67	21.11.2016	Midgard Insect Farm Inc.
68	25.04.2016	Millibeter
69	31.08.2016	Mophgy
70	13.12.2016	Mutatec
71	2016.01.14	New York University
72	2015.05.19	Next Millenium Farms/ Entomo Farms
73	14.05.2016	nextProtein
74	27.02.2017	Nordic Insect Economy
75	19.10.2016	NutrInsecta
76	2016.01.14	ProtaCulture LLC/ GrubTubs (maybe the same company)
77	14.10.2016	Protein Synergy
78	08.08.2016	Protenga
79	19.07.2016	Protifarm
80	2015.05.26	Protix Biosystems BV
81	23.06.2016	Reese Finer Foods Inc.
82	12.09.2016	Rocky Mountain Micro Ranch
83	16.02.2016	SEAJoy - The future is Sustainable
84	13.10.2016	ShellacFinishes
85	19.03.2016	Six Foods
86	2016.01.2	Songhai Integrated System.
87	17.03.2016	Steak TzarTzar/ Hargol FoodTech
88	2016.01.18	Stroever Schellack Bremen
89	15.06.2016	Thailand Unique
90	12.09.2016	Thinksect
91	19.08.2016	Tiny Farms
92	2016.01.14	Topinsect
93	13.10.2016	UNCO
94	27.10.2016	Ycera
95	2015.06.22	Ynsect

Source: Own Database.

Appendix 2 LIST OF INSECT ORDERS

Table 17: Insect Orders

	Insect	No
1	Coleoptera	392.415
2	Diptera	160.591
3	Lepidoptera	158.570
4	Hymenoptera	155.517
5	Hemiptera	104.165
6	Orthoptera	24.481
7	Trichoptera	15.233
8	Blattodea	8.643
9	Odonata	6.650
10	Thysanoptera	6.091
11	Neuroptera	5.937
12	Psocoptera	5.732
13	Phthiraptera	5.136
14	Plecoptera	3.833
15	Ephemeroptera	3.281
16	Phasmida	3.100
17	Mantodea	2.447
18	Siphonaptera	2.086
19	Dermaptera	1.982
20	Mecoptera	769
21	Strepsiptera	624
22	Zygentoma	574
23	Grylloblattodea	542
24	Archaeognatha	514
25	Embioptera	464
26	Megaloptera	380
27	Raphidioptera	271
28	Palaeodictyoptera	233
29	Mischopterida	100
30	Miomoptera	89
31	Diaphanopterodea	74
32	Protodonata	57
33	Titanoptera	46
34	Zoraptera	45
35	Caloneurodea	40
36	Glosselytrodea	30
37	Mantophasmatodea	23
38	Paoliida	14
39	Geroptera	2

Source: (Zhang, 2013)

Appendix 3 GLOBAL SILK PRODUCTION

Table 18: Global Silk Production

Country	Continent	2010	2011	2012	2013	2014	2015
Syria	Middle East	0,60	0,50	0,50	0,70	0,50	0,30
Colombia	Latin America	0,60	0,60	0,60	0,60	0,50	0,50
Egypt	Middle East	0,30	0,70	0,70	0,70	0,82	0,83
South Korea	Asia	3,00	3,00	1,50	1,60	1,20	1,00
Philippines	Asia	1,00	1,00	0,89	1,00	1,10	1,20
Tunesia	Middle East	0,12	3,00	3,95	4,00	4,00	3,00
Madagascar	Africa	16,00	16,00	18,00	18,00	15,00	5,00
Indonesia	Asia	20,00	20,00	20,00	16,00	10,00	6,00
Bulgaria	Europe	9,40	6,00	8,50	8,50	8,00	8,00
Japan	Asia	54,00	52,00	30,00	30,00	30,00	30,00
Turkey	Asia	18,00	22,00	22,00	25,00	32,00	30,00
Bangladesh	Asia	40,00	38,00	42,50	43,44,5	44,50	44,00
Iran	Asia	75,00	120,00	123,00	123,00	110,00	120,00
North Korea	Asia	0,00	300,00	300,00	300,00	320,00	350,00
Vietnam	Asia	550,00	500,00	450,00	475,00	420,00	450,00
Brazil	Latin America	770,00	558,00	614,00	550,00	560,00	600,00
Thailand	Asia	655,00	655,00	655,00	680,00	692,00	698,00
Uzbekistan	Asia	940,00	940,00	940,00	980,00	1100,00	1200,00
India	Asia	21005,00	23060,00	23679,00	26480,00	28708,00	28523,00
China	Asia	115000,00	104000,00	126000,00	130000,00	146000,00	170000,00
Total		139158,02	130295,80	152910,14	159694,10	178057,62	202070,83

Source: http://inserco.org/en/statistics
International Sericultural Commission

Appendix 4 INSECTS FOR BIOLOGICAL PEST CONTROL

Table 19: Surface area of agricultural fields for vegetables and ornamental plants

Organism	Surface area (ha) /year in Germany				
	1993	1996/ 1997	2001/ 2002	2009	2010
Trichogramma brassicae	5.900	5.600	9.443	19.414	22.484
Encarsia formosa	196	403	273	198	1.266
Aphidius – Arten	65	174	174	203	1.042
Lysiphlebus testaceipes	–	1	8	20	315
Diglyphus isaea / Dacnusa sibirica	19	73	95	27	119
Aphidoletes aphidimyza	66	131	134	54	48
Chrysoperla carnea	10	55	40	4	62
Phytoseiulus persimilis	123	125	126	85	332
Amblyseius cucumeris/barkeri	105	174	201	25	1.470
Entomopathogene Nematoden	47	413	> 200	1.272	247
Total	6.531	7.149	10.694	21.302	27.385

Source: (Jehle et al., 2013; p. 81)

Appendix 5 GEOGRAPHIC ORIGIN OF BUSINESSES ACCORDING TO PRODUCT ORIGINATING FROM INSECTS[43]

Table 20: Geographic Origin of Businesses according to Product originating from Insects

Products of Economic Activity		Africa	Asia	Australia	Europe	Middle East	Latin America	North America
Products of Agriculture and Fishing								
	01.49.19 _Other farmed animals , live	x	x	x	x	x	x	x
	01.49.21 _Natural honey	x	x	x	x	x	x	x
	01.49.24 _Edible products of farm animal origin n.e.c. (royal jelly, pollen, propolis)	x	x	x	x	x	x	x
	01.49.25 _Silk-worm cocoons suitable for reeling	x	x (predominatly China)	n.d.	x	x	x	n.d.
	01.49.26 _Insect waxes (honey bee wax)	x	x	x	x	x	x	x
	01.61.10 _Support services to crop production (e.g. pest control for agriculture)	(x)	(x)	x	x	x	x	x
	03.00.7 _Support services to fishing and aquaculture	x	x	x	x	x	x	x
Manufactured Products								
	10.41.19_Other animal fats and oils and their fractions	x	x	x	x	x	x	x
	10.89.19_Miscellaneous food products n.e.c.	x	x	x	x	x	x	x
	10.91.10_Prepared feeds for farm animals	x	x	x	x	x	x	x
	10.92.10_Prepared pet foods		n.d.	n.d.	x	x	n.d.	x
	20.12.22_Colouring matter of animal origin: Carminic Acid	x	n.d.	n.d.	x	n.d.	n.d.	n.d.
	20.15.80 _Animal or vegetable fertilisers n.e.c.	x	x	x	x	x	x	x
	20.30.22 _Other paints and varnishes: Shellac	n.d.	x (predominatly India and China)	n.d.	n.d.	n.d.	n.d.	n.d.
	20.59.51_Peptones, other protein substances and their derivatives	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	20.59.59 _Miscellaneous other chemical products n.e.c.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Water Supply; Sewerage; Waste Management and Remediation								
	38.21.10_Non-hazardous waste treatment for final disposal services	x	(x)	(x)	x	x	x	x
	38.22.19_Other hazardous waste treatment service	x	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Other Sectors								
	Professional, Scientific and Technical Services (Consulting services; Research services in Biotechnology)	n.d.	x	n.d.	x	n.d.	n.d.	n.d.
	Arts, Entertainment and Recreation Services (Other recreational services and Betting Service)	n.d.	x	n.d.	n.d.	n.d.	n.d.	x
	Service of Households and Undifferentiated Goods Produced by Households For Own Use	x	x	n.d.	x	n.d.	x	n.d.
	Wholesale and Retail Trade Services	n.d.	x	n.d.	x	n.d.	n.d.	x

Source: Detailed sources are provided under heading 'Geographic Origin of the Business' pp. 114.

[43] Legend: x: existent businesses were identified; (x) no businesses were found but there is a high probability that business activities exist; n.d.: "no data" means that it is unclear if any related business activities are taken out on this geographic region.

Appendix 6 INDUSTRY LIFECYCLE

Table 21: Industry Lifecycle

Products of Economic Activity	Life Cycle of the Industry	Comment
Products of Agriculture and Fishing		
01.49.19 _Other farmed animals , live	Varies according to geographic region	Scale-up production of insects is practiced in particular for pet food for reptiles, birds etc. targeting zoos, hobbyists etc. Those facilities are in a *mature stage*. However, in the vein of increasing demand for insects as food, feed, and pet food (including cats and dogs), more and more rearing facilities are built up. Pioneers can be found in Europe, North America and South Africa. Those rearing facilities are in a *introduction phase*.
01.49.21 _Natural honey	Maturity Stage	
01.49.24 _Edible products of farm animal origin n.e.c. (royal jelly, pollen, propolis)	Maturity Stage	
01.49.25 _Silk-worm cocoons suitable for reeling	Maturity Stage	Silk is a wellknown commodity. However, research about the use of silk is ongoing and regularly discussed at (international) conferences about sericulture. The variety of application of silk in the industry (i.e., cosmetics, medicine, textile) is an indicator about the versatility of this resource.
01.49.26 _Insect waxes (honey bee wax)	Maturity Stage	
01.61.10 _Support services to crop production (e.g. pest control for agriculture)	Expansion Stage	
03.00.7 _Support services to fishing and aquaculture	Introduction/ Maturity Stage	Introduction Stage (for insects as fish feed)/ Maturity Stage for insects as fish bait
Manufactured Products		
10.41.19_Other animal fats and oils and their fractions	Embryonic Stage	Research about the chemical substances of insects and their use in the industry is just initiating.
10.89.19_Miscellaneous food products n.e.c.	Introduction Stage	
10.91.10_Prepared feeds for farm animals	Introduction Stage	
10.92.10_Prepared pet foods	Introduction Stage	
20.12.22_Colouring matter of animal origin: Carminic Acid	Maturity Stage	
20.15.80 _Animal or vegetable fertilisers n.e.c.	Embryonic Stage/ Introduction Stage	Even though some companies already introduced insect-based fertilizer, research about the composition of insect frass is ongoing. See for instance Wageningen University.
20.30.22 _Other paints and varnishes: Shellac	Maturity Stage	
20.59.51_Peptones, other protein substances and their derivatives	Embryonic Stage	Research about the chemical substances of insects and their use in the industry is just initiating. See for instance: ChitoTex EU project or Yellow Biotechnology
20.59.59 _Miscellaneous other chemical products n.e.c.	Embryonic Stage	Research about the chemical substances of insects and their use in the industry is just initiating.
Water Supply; Sewerage; Waste Management and Re		
38.21.10_Non-hazardous waste treatment for final disposal services	Embryonic Stage/ Introduction Stage	A number of start up companies that produce insects as food or feed are trying to reuse organic waste streams as insect feed (ie., originating from supermarkets or from food processing). This practice is subject to legal restrictions which, however, differ according to the geograpic regions. Using insects only to convert organic waste without further processing them seems not to be an attractive option to many companies.
38.22.19_Other hazardous waste treatment service	Embryonic Stage/ Introduction Stage	see comment above
Other Sectors		
Professional, Scientific and Technical Services (Consulting services; Research services in Biotechnology)	Embryonic Stage/ Introduction Stage	Insects as a resource have been structurally disregarded and begin to receive increasing attention in the framework of the Bioeconomy. See also Dimension: Applied Research about Insects.
Arts, Entertainment and Recreation Services (Other recreational services and Betting Service)	Maturity Stage/ Decline	
Service of Households and Undifferentiated Goods Produced by Households For Own Use	Introduction/ Maturity/ Decline Stage	In consumerist countries in Europe, it is possible to buy insect hives that enable households to rear their proper insects for subsistance. However, this technology requires further fine-tuning (*Introduction Stage*). In developing countries that practice entomophagy, insect rearing at household level is a tradition (*Maturity level*). However, the wealthier people become, the less do they rear insects themselves. More than that they tend to discard insects from their diet. (*Decline Stage*)
Wholesale and Retail Trade Services	Introduction	

Source: Clustering based on section 3.5 where the sectors are described in detail.

Appendix 7 INTERVIEW QUESTIONNAIRE

- Could you shortly describe your business? What is your value proposition? In which consumer and geographical markets do you operate in?
- I saw that you started the project in Madagascar but then transferred it to Malaysia. Why?
- What is the development stage of the company?
- What were the motivations of the founders to found a business based on insects?
- On your webpage you describe multiple types of waste including offal. Can all types be used as feedstock for the BSF and then transform the BSF into fish feed?
- Why did you focus on insects as feed and not as food?
- What does sustainability mean for you?
- From what I read on the webpage, I understand that you consider sustainability rather from an environmental and economic perspective. Is that correct or do you also consider specifically social aspects?
- Which values would you say your company has? What defines your business?
- Your business shows clear sustainability characteristics. Is it working in some way different from a conventional business?
- If you would have to characterize your company and prioritize these characteristics what would be characteristic no 1, 2 and 3?
- Is anyone in the company trained in regard to sustainability?
- I have seen that you have worked at an NGO and are concerned with ethics. Do these concerns play a role in your function in the company?
- The more your company grows, the more it will be relevant to have installed directives or similar guidelines that promote sustainability. Are you planning to introduce such orientation tools?
- Which business logic lies behind the sustainability orientation of your business
- Do you see a trend towards sustainability? (especially looking at the case in Malaysia)
- Which stakeholders do you consider an important part of your business?
- What characteristics does your technology have to be considered sustainable?
- The whole infrastructure of your business does to a certain extent present an environmental burden. Is this an aspect that you consider in your decision-making?
- Considering your value chain: To which extend is it sustainable in your opinion & where would you like to see improvement?
- You mentioned before that you can use a broad array of waste to feed your BSF. How is the legal situation for such processes in Malaysia?
- In order to grow, investors are important to expand the business. Do you use any sustainability criteria to select investors? Do you take any measure to avoid investors that are not in line with your orientation towards sustainability?
- How do you evaluate the success of your business? Do you consider other aspects than monetary value creation?

- Do you see any risks that the Insect Economy may hold back from developing sustainably in general? Which are they?
- What do you do to anticipate them?
- Are there any noticeable gaps in your company to be fully sustainable? Which limits do you see?
- How do you confront these limits?

Appendix 8 MAXQDA Codes and Codings

Liste der Codes				Codings	Doku-mente
Codesystem				834	20
1	Business Model Building Blocks related to 'Insects as'			2	2
2		Insects as Food		9	4
3			Value Prop.: Insects as Food for End Consumers	5	2
4			Value Proposition: Insects as Food Ingredient for Food Producer	3	2
5			Value Prop.: Logistics betw. Insect Prod. & End Cons./ Food Pro	5	2
6			Value Prop.: Technology	3	2
7			Customer: Food Producers	2	2
8			Customer: End Consumer	2	2
9			Key Activities: Technology production for insects as food	4	3
10			Key Activities: Processing of the Insects (not production)	1	1
11		Insects as Livestock Feed and Pet Food		2	2
12			Insects as Pet Food	3	3
13			Value Prop.: Insects as Ingredients for Compound Feed	8	6
14			Value Prop.: Insects as Feed for Small holder-Farmers	3	2
15			Value Prop.: Logistics between Insect Producer & Feed Comp	4	1
16			Value Prop.: Technology	3	3
17			Customer: Farms/ Backyard Chicken market	8	4

18			Customer: Feed Producers				4	4
19				Animal feed ingredients			2	2
20			Animal Species				0	0
21				Acuaculture			6	5
22				Poultry			8	5
23				Swine			1	1
24			Key Activities: Technology manufacturer for insects as feed				3	3
25		Insects as Organic Waste Converters and Fertilizer					17	11
26			Fertilizer				5	5
27			Value Proposition: Insects as Waste Management Tool				5	3
28			Customers: Waste Producers				3	2
29			Types of Organic Waste				1	1
30				Post-Consumer Waste			1	1
31				Pre-Consumer Food Waste			5	4
32					Grains from Farms		1	1
33					Organic Waste from Food Producers		3	2
34					Food waste frm food distributors and grocery chains		2	1
35				Alternative Waste Streams (Sewage, Manure, Abattoir Blood)			1	1
36					Bioconversion of pig manure		1	1
37				Other Types of Organic Waste			2	2
38		Provider of diverse bio-based Materials					2	2
39		Food vs Feed					4	3
40			Insects can help to solve the Waste Problem				1	1

41			Urgently needed substitution of Fishmeal for Livestock Product.	1	1
42			Insects as Feed: Too many people prefer eating meat	1	1
43			Insects as Food cannot use the Principle of Circularity	2	1
44			Insects as Food leapfrog Conventional Livestock Industry	2	1
45			People are not interested in eating insects	2	2
46			Feed industry primarily strives for efficiency/ not sustainable	2	2
47			Perverse incentive to support conventional livestock industry	1	1
48			Insects as Food: Feed for insects in conflict with human food	4	3
49			Philosophical reason to produce food instead of feed	1	1
50	Business Model Innovation Grid			0	0
51		Business Model Building Blocks		0	0
52			Key Activities	33	16
53			Value Proposition	17	7
54			Key Resources	12	7
55			Customer Segments	13	11
56			Channels	6	5
57			Key Partners	10	5
58			Customer Relationships	0	0
59			Competitors	0	0
60			Revenue Stream	0	0
61			Cost Structure	0	0
62			Other Stakeholders	0	0
63		Industrial Symbiosis		22	10

64		Bottom of the Pyramid		5	2
65		Circular Economy: Modularity		14	7
66		Product Service Systems		9	3
67		Empowerment		9	4
68		Circular Economy: Zero Waste		14	11
69		Collaborative Approaches: Institutional Entrepreneurship		15	6
70			Institutional Entrepreneurship	11	5
71			former foodstuff"/ "Preconsumer waste"	3	1
72			Build up an infrastructure for Insect Consumption	1	1
73		Localization		10	4
74		Reuse, Recycle, Remanufacture		10	6
75		Producer Education, Comm. & Education		2	1
76		Licensing, Franchising		2	2
77			Gemeinschaftsunternehmen gründen	1	1
78			patent system	1	1
79			Leasing	1	1
80		Incubators and Entrepreneur Support Models		3	1
81		Product Longevity		2	1
82		Radical Transparency about Societal Impact		2	1
83		Frugal Business		1	1
84		Move to Renewables		1	1
85		Green Chemistry		2	2
86		Consumer Education		4	3

87		Hybrid Organization		3	1
88		Open Innovation		0	0
89	Sustainable Development Goals			1	1
90		SDG 1_End Poverty		0	0
91		SDG 2_Zero Hunger		4	3
92		SDG 3_Good Health and Well-being		1	1
93		SDG 5_Gender Equality		4	2
94		SDG 7_Affordable Clean Energy		0	0
95		SDG 8_Decent Work and Economic Growth		4	3
96		SDG 9_Industry, Innovation and Infrastructure		26	13
97		SDG 10_Reduced Inequality		18	6
98		SDG 11_Sustainable Cities and Communities		7	3
99		SDG 12_Sustainable Production and Consumption		42	17
100			System Change	2	2
101			develop a resilient food production system	8	4
102		SDG 13_Climate Action		3	2
103		SDG 14 & 15_Life below Water and Life on Land		16	10
104	(Global) Challenges			2	2
105		General Issues related to Food Production System		6	4
106			Tackle the health and antibiotic problem in aquaculture	1	1
107			Stop speculation with food	1	1
108		Resource Scarcity		1	1
109		Energy Crisis		0	0

110		Structural Unemployment/ Social Inequality				7	4
111		Climate Change				1	1
112		Urbanization				1	1
113		Health Issues				2	2
114		Waste Production				8	6
115		Malnutrition and Food Scarcity/ Contaminated Food				4	3
116		Environmental Degradation/ Depletion of Fish stocks				13	9
117		Biodiversity Loss				0	0
118			reduce pressure from wild harvesting: Not mentioned			1	1
119	Sustain.from Busin.Case Persp.: Business/ Social/Natural Case					9	7
120		Business case				2	2
121			Demand for Sustainable Protein			5	5
122				Nutritional Profile		5	5
123					Health benefits	6	4
124			No Products that Enable home-based Protein Production			2	1
125			Provide solutions to waste producers to recycle their waste			4	3
126			Provide ingredients to farmers to produce own Animal Feed			1	1
127			Cost reduction/ advantage			4	2
128				Cheap Insect Feed		2	2
129			Natural Feed			3	3
130		Social case				22	14
131			Provide farmers with opportunities and produce insects			1	1
132			develop a special program for Africa to feed Africans			1	1

133				Health benefit	1	1
134				Social aspect first	1	1
135			Natural Case		18	11
136				Upcycling any type of organic waste	1	1
137				Upcycling of consumer waste	1	1
138				upcycling of pre-consumer waste	1	1
139				Focus on environmental benefits	2	1
140			Triple Bottom Line		9	5
141				Business Case for Sustainability	5	3
142		Diffusion Dynamics			2	2
143			Limited Acceptance of Local Culture to Consume Insects		3	3
144			Econ. Constraints in Dev. Countries to Finan. Technology		2	2
145			Regulations and Bureaucray		4	3
146				Bureaucratic Processes	1	1
147				Loose regulations in regard to waste in develop. countries	2	1
148				EU legisl. prohibits organic waste as feedstock for Insects	8	6
149				Insects are not allowed to be fed with organic waste	9	6
150				Legal hurdles for exportation	1	1
151			Compatib. with Industrial Processes in Livestock and Feed Prod.		5	3
152				Required Rethinking of Feed Composition when introd. Insects	1	1
153				Economic competiveness with fishmeal required	4	4
154				Feed producers dont accept single source suppliers: Risk	1	1
155				Keep up with quantity to be attractive for feed producers	1	1

156				Imperatives of the Industry: Feed Production	1	1
157				Farmers are conservative/ risk averse	1	1
158			Cultural Awarness of 'Sustainability'		1	1
159				Culture of a country is not focused on sustainability	3	2
160				Primitive capitalism	2	2
161				No awareness about sustainability in the market	1	1
162				Little Awareness for Environmental Issues	1	1
163		Sustainable Business Drivers			0	0
164			Drivers related to Sustainability		4	4
165				Willingness to support local produce	6	3
166				Increasing Price Competitiveness with Conventional Products	1	1
167				Increasing Consciousness for Sustainability and Willingness to	5	4
168				A lot of the food manufacturers approach as because the PR	1	1
169				Demand for Fishmeal-free, sustainable food products	2	1
170				Changing job market: Increased competitiveness as sustainable e	1	1
171				Investors Awareness for ESG (Environmental Social and Governanc	7	6
172				Expecations of Consumers for more Sustainable Business Behavior	1	1
173				Cultural Opening to more sustainable lifestyle	2	2
174				Belief of Entrepr. that Sustainab. leads to better Performance	2	2
175			Drivers related to Insects		0	0
176				Shortage of Insects considered Delicacies (Premium Price)	1	1
177				Demand for Insects as Food/ Means to create Brand Value and Bra	2	1
178			Drivers related to Adding Value to Waste		0	0

179			Hugh Potential to Reuse Waste		2	2
180			High Cost of Waste Production		6	4
181			Increased awareness and regulation to minimize waste and promot		1	1
182		Drivers related to Problems in the Food Value Chain			0	0
183			Pressure for Alternative Sources of Protein (Substitute for Fis		6	4
184			Environmental Challenges in the Food Chain		2	2
185			Lack of Available Fishmeal		1	1
186			Feed Spoilage due to Long Transportation Distances		2	1
187			Cost Pressure due to high Protein Prices		1	1
188			Demand for Alternative Model to Conventional Farming Industry		2	1
189		Other Drivers			0	0
190			Food compatible with religious dietary Practices		0	0
191				kosher	2	1
192				halal	1	1
193			Demand for High-Quality Petfood		0	0
194				premium pet food.	1	1
195			Demand for Fertilizer		1	1
196			Do-It-Yourself-Trend		3	1
197				Homegrowing-Markt	1	1
198	Risk Factors				2	2
199		Lack of Collaboration			2	1
200		Overengineering of the Insect Economy			7	1
201		Lack of Research			2	2

202		Implementation of Decentralized Model not Viable	1	1
203		Disease Break out Due to Lack of Standards for Insect Productio	3	1
204		Release of Invasive Species Related to Unsafe Rearing Cages	1	1
205		Interest in the Sector for Pure Economic Reasons	1	1
206		Breeding Techniques for Insects Analogous to Livestock Product.	3	2
207		Potential of Feeding Insect with Organic Waste cannot be Exhaus	1	1

Appendix 9 Business Model Innovation Grid and the Insect Economy

Table 22: Business Model Innovation Mechanisms in the Insect Economy
Comment: Mechanisms highlighted in *italics* refer to newly identified mechanisms in the Insect Economy

Business Model Innovation Mechanism	Definition (Source: http://vlaanderen-circulair.be/bmix/index.php if not indicated otherwise)	Examples
Circular Economy: Zero Waste	Closed-loop business models include products and business processes designed in a manner that enables waste at the end of the use phase of a product to be used to create new value.	• Zero-Waste-Production (Fo2, Fo3, Fo9, Fe11, M3) • Fo2: Insect Frass is converted into Fertilizer • "We strive for a zero waste cycle. The larvae can eat through most objects however even through a whole water melon, they will eat through the whole rime but that will be left. So if you do pulp the food waste you trade it like a salsa-like consistency, the larvae can't break it down more efficiently. So every now and then you have peal of an avocado etc that will be shifted out of that process." [M3_93] • "Frass: we've been selling that to urban gardeners so as an organic fertilizer. And we're taking steps to be scaling up into larger agricultural markets but, for right now, we've had a lot of good traction in the urban consumer markets." [Fe5_22] •
Circular Economy: Modularity	Modularity refers to designing products or systems in a way that they are relatively independent but that their components or parts are interlocking. This makes these systems flexible, adaptive and scalable. (Ellen Macarthur Foundation, 2013). It is, therefore, a fundamental product design principle to achieve the circular design, together with, purer materials flows, and design for easier disassembly. Modularity	• "Container solutions particularly for food and beverage processors" [Fe2_92] • "We can scale it up as large as want. As shipping container or an existing building" [Fo4, 15] • "Farm modularity means our farms can be built anywhere and consistently provide reliable, low-cost yield." [Fo1_53]

	enables easy versatility, scalability, and adaptability. In the business context, this means more leeway for innovation and the development of diversified value chains. In a global context, this is at the heart to build resilience in a fast-changing world. (WEF, 2014b)	
Industrial Symbiosis	Industrial symbiosis is a process-orientated solution turning waste outputs from one process into feedstock for another process or product line.	• Sourcing waste from large manufacturers • Examples: "We are taking food waste from industrial manufacturers (e.g. bakeries) that would otherwise go to landfill" [Fe3_65] • "We are looking into container solutions particularly for food and beverage processors and take their bio-solids - and not their waste. These large food and beverage process services are required to treat their waste water, so they are left with large amounts of bio-solids and that's what we are looking to work with." [Fe2_92] • "Our goals are to produce a sustainable insect-based protein source that would be used in the manufacturing of animal feeds. We do so by recycling food waste and by feeding it to the BSF larvae. As the larvae eats through the food waste, they convert it into a quality fertilizer and then we shift the larvae from the fertilizer that can be sold […] The larvae are then processed into a protein and a fat ingredient. With the goal of replacing fishmeal and fish oil. So it is really trying to undercut overfishing, and simultaneously, tackle the food waste issue that we have in the US." [M3_52-53] • Company Fe4 "has commercialized the upcycling of pre-consumer waste food, including fruits, vegetables and grains, using the larvae of black soldier flies; which solves two global food issues: loss of food nutrients through waste and the unsustainable practice of using fish and soybean products to feed fish, poultry and pets." [Fe4_11] • "The waste foods that we process as feedstock to create protein and oils as feed ingredients for fish and poultry, often comes back to us in the form of additional waste food to complete the cycle. In addition, our by-product organic fertilizer is used to grow organic grains and vegetables, the waste from which we often see returning to us as feedstock to create more organic fertilizer." [Fe4_41]

		• "We use surplus fruit or "unpretty" fresh fruit which we source from farms, food producers, and grocery stores." [Fo8, 61] • "In the Singapore context, the [business] model is very much focused on insects and particularly the black soldier fly which is our insect of focus as a waste management tool. In Singapore, waste has cost - a quite high price actually and the current model is incineration. Pretty much 100percentpercent of the waste is incinerated. So, the model we are pitching is a way to use nutrients that are other ways going to the incinerator: bring them back into the cycle, use the high quality nutrients that are available in Singapore during all stages of the value chain and bring them back to increase self-sufficiency which is a big issue. It is fueled by the waste aspect of avoiding cost and increasing self-sufficiency while depending on imports. [M1_4]
Reuse, Recycle and Remanufacture	To reuse is to use an item again after it has been used. This includes conventional reuse where the item is used again for the same function, and new-life reuse where it is used for a different function. In contrast, recycling is the breaking down of the used item into raw materials which are used to make new items. Remanufacturing is the process of disassembly and recovery at the module level and, eventually, at the component level. It requires the repair or replacement of worn out or obsolete components and modules.	• "Instead of building new facilities, we are using empty warehouses. We use the cover of the warehouses and inside we build the climate controlled rooms. We are not building something new but we are only using the existing infrastructure." [Fo2_106] • "We've been looking at is, you know, are there ways we can be efficient with our capital by retrofitting existing, underutilized infrastructure. There's a lot of abandoned warehouse space." [Fe5_138] • "So we're working with a lot of pig farmers to go retrofit abandoned piggeries for example with our modular insect farming facilities." [Fo4, 12] • "The construction materials that we try to use are used as well. They are leftover parts. They're also cheaper that away." [Fo4, 34] • "We can scale it up as large as want. As shipping container or an existing building" [Fo4, 15] • "One of our key points is that we want to reuse buildings. We are not focusing on building doing new constructions. So we make use of what we currently find, for example old farms." [Fo3, 61] • "We are searching for existing buildings to enter" [Fo8, 70

Move to Renewables	This spans options from substitution of finite materials with renewable materials, such as replacing metals with natural and fiber-based materials, through to system-level renewable power generation systems.	• Substitution with Renewables. Example: “The primary products produced by [Fe4] are whole dried larvae, protein meal and animal oil are renewable and are direct substitutes for unsustainable and resource intensive feed ingredients such as fishmeal, soybean meal, coconut oil and palm kernel oil as feed ingredients for fish, poultry, pets and specialty zoo animals. Fe4’s products are renewable as all of the inputs in the process come from renewable sources. [Fe4_42]
Green Chemistry	Green chemistry, also called sustainable chemistry, is a philosophy of chemical research and engineering that encourages the design of products and processes that minimize the use and generation of hazardous substances.	• Using chitin as a sustainable product [Fe3_67]
Product Service Systems	Product Service Systems (PSS) is in place when a firm offers a mix of both products and services, in comparison to the traditional focus on products.	• Company W1 offers a logistic concept which connects food waste producers from cities with small-scale farmers to so that they can achieve *feed autonomy*. This autonomy is achieved by providing the farmers a kit consisting of a small scale insect rearing station and insect larvae and on a regular basis delivering food waste. The larvae feed on the food waste while the farm animals feed on the insect larvae that grows on the waste. Thus, this business model adapts to pattern of a physical multisided platform (Osterwalder and Pigneur, 2010). • [We are] “a logistics company in a way and hatchery and a black soldier fly equipment manufacturer. Those are the three things that we do. In other words, we are the hatcheries supplying the hatchlings to farmers, we are the distribution standard that drops of the food waste at the farm and we design the equipment that the farmer can then lease or purchase.” [W1_16] • “We are offering rearing technology to the farmers and then we offer the whole process how to rear insects and then we tell the farmer's how to do that at a high level and then we buy all that from the farmers and sell it to the food companies. So if you want to start farming, we can offer you everything that you need for that.” [Fo3_61]
Radical Transparency about Societal Impacts	Consumers, governments, and companies are increasingly demanding details about the systems and sources that deliver the goods. They	• “The next point by which we try to put pressure on ourselves is that we are writing a manifesto where we are committing to things, and through transparency to show how things currently work and what needs to be improved.” [Fo5_125]

	worry about quality, safety, ethics, and environmental impact. Farsighted organizations are directly addressing new threats and opportunities presented by the question, "Where does this stuff come from?".	
Product Longevity	Product durability and longevity through product redesign potentially slows product replacement cycles.	• "We have designed [our product] so that it is as durable as possible and it is easy to repair. That is to say, it is designed to be modular to a certain extent, and that individual parts can be easily repaired. Otherwise, it would also be logistically difficult for us, because the product also has a certain size. Instead, we can send individual components, which the user himself could exchange." [Fo7_53]
Frugal Business	Frugal business models typically focus on provision of products and services to low-income markets, often in extreme poverty. The business models take complex product concepts and redesign them to pare down to their base functionality.	• „We are working with the farmers. They create a [hoop# house with a roof structure and we put in the equipment. The farmer gets going for $20 to $25 [investment] till they hit production capacity, nobody has to buy the land, nobody has to wait on a permit." [W1_16] •

Consumer Education, Communication and Awareness	According to Plan-C, consumer education models sensitize consumers about the impact of their purchases. It induces consumer activism that is based on the concept of dollar voting. Examples refer to webpages that create transparency for conscientious consumer behavior. In the example of the Insect Economy, consumer education is a fundamental part of convince consumers about the benefits of eating insects and therefore make more sustainable purchasing decisions.	• Awareness raising takes place, e.g.:
		  • Through campaigns e.g. the NGO little Herds or the Edible Insect Day
		  • As part of the business model to gain customers
		• "So, [our product] is supposed to show that you can feed yourself a bit outside of your habitual food ideals, or a bit outside of the comfort zone, even with insects or whatever" (Fo7_75).
		• "I can already say that with our presentations, we have reached more than 4000 people, which then also spread the word." [Fo5_85]
		• "I would like to attribute a lot to what we've done in the media: social media advance and all that in past two years." [Fo4_10]

***Producer* Education, Communication and Awareness**	Analogous to mechanism above, entrepreneurs educate, raise awareness and communicate with their clients about their impact and opportunities to create positive social and environmental impact. To be successful they strategically align economic success and sustainable (non-monetary) activities by means of creating a business case for sustainability.	• "Another great example that I use from a marketing perspective is every 20 to 25 liters of food waste that we pick up brings back one dozen eggs and suddenly that image of [our product] is that it brings back a dozen eggs, versus I educate them. Then I explain that if we were to compost that amount of waste, we would create about 20 cents of compost or $6 a dozen eggs. And so they see that huge shift in valuation between making compost and making food. And so, because of the fact that it has to happen so close to the city, the food waste producers provide nutrients to local farmers. You can't outsource that, you can't take that food away and bring it to Ecuador and say I'm going to do it here because wages are cheaper in Ecuador." [W1_74]
Open Innovation	"The Open Innovation paradigm treats R&D as an open system, and stresses the relevance of coupled processes, linking outside-in and inside-out flows of ideas by working within alliances of complementary companies. Their objective is to leverage the disparate knowledge assets of people and to integrate different but interrelated knowledge bases inside and outside the organization (Fichter, 2009; pp. 357)	• Open Innovation in the Insect Economy takes place by collaborating with • Chefs to develop insect-as-food solutions (Fo5) • Universities and research institutes (e.g., University of Wageningen, VENIK, Insectcentre, Lowe Center) • Forming part of a research project (e.g. ChitoTex, CHITINSECT)
Licensing, Franchising	*Licensing* is defined as the granting of permission to use intellectual property rights, such as trademarks, patents, or technology, under defined conditions. *Franchising* is a form of business organization in which a firm which already has a successful product or service (the franchisor) enters into a continuing contractual relationship with other businesses (franchisees) operating under the franchisor's trade name and usually with the	• Licensing, Patented Solution (e.g., Fe3, Fe7, M3, W1) • Franchising (Fe7)

	franchisor's guidance, in exchange for a fee. (Investorworld, 2017)	
Collaborative Approaches: Institutional Entrepreneurship	Shepherd and Patzelt (2011; p.148) define an institutional entrepreneur as an "actor that has an interest in developing new institutions or facilitating change in existing institutions and leverages resource to achieve change."	• In the case of the Insect Economy, collaborative approaches refer to lobbying to allow insects as food and feed. It takes also place to create standards for insect production in order to avoid risks that could hamper the industry development for the insects as food and feed sector altogether. • Example: "In the past three years, we have very much advocated for changing the law that is to say, we have really given the impulse that the law has changed [9:59]. We have worked very closely with the authorities, so that we are now at the point where it is now legal for May 1 [2017] [to consume insects as food]." [Fo5_79] • „we're working with regulators to solve these problems [referring to using organic waste as insect feed]. So I actually was at the FDA a few weeks ago speaking with folks there about what it would take for us to get some of these alternative feed ingredients into our farms." [Fe5_97] • "We are building a quality chain for insects. Because it doesn't exist yet like a poultry business or a regular business where you have very strict regulations and know exactly what to do. This is what we are thinking to build up. Otherwise it is not going to be a big business and it will remain a niche business all the time. We also want to share best practices with our customers. This is the way you can be rearing quality insects" [Fo3_67] • organic material which is "perfectly safe, but from the moment that the concept of "disposal" prevails, then this product is by definition waste. It is unimportant how good the product is; it is no longer introduced into the feed chain. We are trying to change the laws." [Fe7_17-23] • "What IPIFF would like to establish is the concept of "former foodstuff or pre-consumer waste"… Our approach is to establish the concept of pre-consumer substrate and to obtain permission from the EU to use this for the insects. [Fe7_16]

Incubators and Entrepreneur Support Models	The Business Model Innovation Grid does not provide cases about this mechanism yet.	• In the case of the Insect Economy, collaborative approaches were mentioned in at least two occasions: • "in Vietnam, we cooperate with [an insect company]. [The founder] has learned from [us] and has taken over most of the technology. [The company] works on a low technology basis due to lack of funds. [We] have developed bioreactors which, however, have higher costs. [We] help to collect investment funds for [the start-up in Vietnam]." [Fe7_40] • "I also support some young entrepreneurs who can become my competition. But we also have to be a significant industry and then we have pioneering advantages where the margin is bigger, but with increasing production automatically the margin goes back. But I am convinced that one must be optimistic" [Fe7_109].
Localization	Localization is the practice of embedding a business near its consumer market, sourcing the resources locally and adjusting the products and services to local needs.	• "We talk to chefs in restaurants, they like this whole notion that they are supporting local agriculture, that's what the chefs' want to support, it's not about global warming, it's about supporting American farmers you see? Because you buy from American farmers and the more they can support the American farmers, the more that they can purchase quality ingredients from locally". And, "I really believe that the model for insects in the future is not a centralized facility that has a huge capital infrastructure but actually a decentralized infrastructure." [W1_74]. • "Our idea is also opposite of what is actually fishmeal and soybean market today. Fish and soybean are commodities which produced at the other side of the world and travelling on the cargo container and going to Asia from South America, etc. We think that this bio-conversion allows to produce protein locally and to be used on the local market." [Fe11_31] • "And so I really believe that the model for insects in the future is not a centralized facility that has a huge capital infrastructure but actually a decentralized infrastructure" [W1_16] • "You have very long storage periods, there's a lot of spoilage and a lot of transportation challenges. So we can help a farmer who is in Washington state, instead of having to deal with soy meal that's been imported from Brazil and is 10 months old, if we can offer an-other product that was grown just last week, you know, just a couple of miles from their facility that's a huge selling feature for that customer." [Fe5_71]

		• "Ideally we would be developing shipping container solutions and move it to partners and ideally we would have somebody else to post process the insect but we were I'm sure about how we can go about it." [Fe2_92]
Bottom of the Pyramid	Bottom of the Pyramid Markets are markets where people live with less than $1.90 per day. Thus, the intention with the Bottom of the Pyramid-concept is to reduce poverty and inequity of the very poor by giving them access to markets.	• "In [Africa], we have for villages in which we work. Each Village has about 125 farmers who work with us. And basically, the idea is that we give them an individual farming equipment, which allows them to produce maybe two or three kilos of palm weevil larvae. That is enough for most people to just feed them and their own family. Supplemental protein requirements but we have a few farmers, 20 percent of the 500 farmers who are very motivated who actually set up multiple small farms so instead things just 1 or 2 kits, they actually bought 10 kits to produce 20 kilos trying not to serve only their own family but they are now selling to their community" [Fo1_91] • "The business model is as follows: the partner breeds turkeys, chickens, guinea fowls and quail, sold as kits together with a set of feeds sold to smallholder farmers. The concept looks like these farmers are buying 20 of these kits. Two of them are need for themselves and the rest is sold at the roadside. So far, we have reached a thousand of these smallholder farmers." [Fe7_44] • "Why shouldn't farmers and small-farmers not do it themselves rather than having their waste being shipped somewhere and then insects are produced and then the insects sold back to the same farmer at a premium. Why not empower farmers to do it themselves?" [M1_31]
Empowerment	In the context of the Insect Economy, the term refers to improving the market power of underprivileged businessmen particularly in wealthy countries to enlarge their choices, to reduce inequity and to enhance their active participation in society.	• For example, in Finland our traditional farmers (family farmers) are really suffering because the prices of meat are really low and basically they cannot live without European Union's support. The farming business is not profitable in Finland but farmers are always looking for new businesses in order to survive on the countryside. So this is one possibility in how we create benefits for people. […] So we sell whole solutions to the farm for a certain amount. Then we also sell support and how to do the maintenance and then we buy everything back what they produce. [Fo3_96]

		• "And so what we're doing is we're really empowering farmers to make their own feed independent of big farms of soy (#00:18:46#) which is a huge problem and hasn't been done before. And the way that is by integrating our cities with their farms" [W1_16] • "What we're doing is, we're really empowering farmers to make their own feed independent of big farms of soy." "And that's why I'm such a big advocate of the decentralized feeds model, empowering farmers to make their own feed." [W1_34] • "The business model is as follows: the partner breeds turkeys, chickens, guinea fowls and quail, sold as kits together with a set of feeds to smallholder farmers. The farmers are buying 20 of these kits. Two of them are needed for themselves and the rest is sold at the roadside. So far, we have reached a thousand of these smallholder farmers. Our goal is to reach 2000 to 5000 farmers" [Fe7_44] • "Why shouldn't farmers and small-farmers not do it [referring to insect rearing] themselves rather than having their waste being shipped somewhere and then insects are produced and then the insects sold back to the same farmer at a premium. Why not empower farmers to do it themselves?" [M1_31] • Company Fo6 empowers rural female farmers [Fo6_135]
Hybrid Businesses	These 'hybrid' organizations mix social and entrepreneurial practices and objectives (Belz and Binder, 2015). Thus, they combine demand-based market logic with a need-based social logic to weave social and environmental dimensions of value creation into the fabric of the organization. Hybrid businesses can have different legal forms, such as the L3C Statute (Low Profit Limited Liability Company), and the Benefit Corporation. (Stubbs, 2017)	• Company Fo3 is an *Ethical company*: The interviewee describes it as following: „In a normal company, me as a CEO could decide to change the value proposition from insect as food to insects as feed. But the status of an *ethical company* would prohibit such a decision-making. The rules of the company would require the member of the board to accept that we change towards insects as feed. This of course also plays for other changes in direction that are not included in our original idea and that might affect ethical and sustainability rules we have written internally." [Fo3_84] • "I mean we could make some compromises in order to be more profitable, intervene faster and more efficient. But this is something that we are not going to do. So in regards to this we still have to run an extra mile for that but still if you really want to change something it has to be from the bottom." [Fe3, 90]

		• "We have said, 'precisely here it makes sense for us to advocate a social change. Whether this is will become economically or not, is a secondary issue." [Fo5_80]

Appendix 10 Business Drivers (for Sustainability) in the Insect Economy

Table 23: Business Drivers (for Sustainability) in the Insect Economy

CATEG.	DRIVERS FOR SUSTAINABILITY	EXAMPLES FROM INTERVIEW RESULTS
TREND FOR SUSTAINABILITY	**Willingness to support local produce**	"We talk to chefs in restaurants, they like this whole notion that they are supporting local agriculture, that's what the chefs' want to support. It's not about global warming, it's about supporting American farmers you see? Because you buy from American farmers and the more they can support the American farmers, the more that they can purchase quality ingredients locally." [W1_74]
	Increasing Consciousness for Sustainability and Willingness to Pay by Producers (and Consumers)	"Large food companies are willing to pay 10-15 percent more for sustainable products because consumers are demanding them. 10 to 15 years ago, the product would not have had the same potential because nowadays the consumers are aware of health problems and animal welfare issue which has not been the case before." [Fo8,_47]
	Cultural Opening to more sustainable lifestyle	"I think we have a certain cultural opening. We are more open to new things. We have an increasingly educated population, we have a movement where the individual becomes more and more important. Where one also reflects about: where do certain things come from? I think these are all tendencies that are now the right time to offer insects as food." [Fo5_124]
	Increasing Price Competitiveness with Conventional Products	"… in this triad, we must carry on to become economic. In our biological pest control, it is quite clear why, in the area where we are not only more ecological, but also more economical, we have won. There everyone is an environmentalist, but if the products are more expensive then there is a threshold"… [Fe7_100]
	Demand for Fishmeal-free, sustainable products	"Some companies really want to market some fishmeal-free products, fishmeal-free compound feed, and those companies who want to market the sustainability they want to work with the insect industry. […] everybody is craving for insect protein in the market and no one can find it because not a lot are producing. [Fe11_106] "Fishmeal is becoming a more expensive protein source, less accessible. Therefore, I think there will be a trend." [Fe2_127]

INSECTS	**Changing job market: Increased competitiveness as *sustainable* employer**	"In your opinion was the market ready already 10 to 15 years ago?: No other start-ups doing exactly what we do in the 90s or in the 80s even could never go where we are now. We are lucky, timing, there are people willing to quit their jobs in doing what we want to do for lower wages These are all things are also part of the coming of age of sustainability as a driver." [Fe1_78-9]
	Investors Awareness for ESG (Environmental Social and Governance Criteria)	"Both major investment funds that own [Fe4] are highly visible as investing only in sustainable businesses or technology to improve global agricultural sustainability." [Fe4_28]
	Demand for Insects as Food/ Means to create Brand Value and Brand Recognition	"A lot of the food manufacturers approach as because the PR." [Fo2_81] "3 years ago there was almost no market but in the last three years the market for insect protein grew. […]The demand is much higher than the supply because the cricket farmers are not able to follow the demand. So, it is a very interesting and attractive market for us and relatively easy to reach. I can tell you that there is a long-term long list of customers (food manufacturers) in the US to fulfil orders. This is why we are focused on the US market but in a year or so we will have other markets open for us as well." [Fo2_78]
	Shortage of Insects considered Delicacies (Premium Price)	"Almost half of the world population is consuming insects as part of their diet. The most widely consumed insects are grasshoppers. They are consumed in Africa, Asia, central America, middle East. Where they are consumed they are considered a delicacy. This means that where they are sold they have very high prices. Today over 99 percent of consumption is supplied by collecting in the wild and on low season there is a limited availability of four to six weeks a year and on high season when they are available, they are double the price of beef which is something shocking. Off-season grasshoppers can be 10 times or even 15 times more expensive than beef." [Fo2_58]
	Changes in Legislation	Legislative hurdles hinder the introduction of insects as food or feed. Interviewee Fe9 referred to the following changes by the EU commission: • Novel Food Legislation allows insect consumption under EU Regulation 2015/2283 • The EU allows insects for aquaculture (Regulation (EU) N° 2017/893)
ADD VALUE TO WASTE	**Increased awareness and regulation to minimize waste and promote resource recycling**	"Improved communication globally on sustainable practices and the goal of a circular economy" (Fe4_21)
	High Cost of Waste Production	"In Singapore, waste has cost - a quite high price actually, and the current model is incineration. Pretty much 100 percent of the waste is incinerated." "Incineration is actually waste-to-energy. So, they are burning it and trying to recover some of the energy contained for electricity. But that's another discussion because if you have organic

		waste and 70 percent of moist, you can hardly produce any energy of that. 3.final disposal of the remaining ashes on the landfill and all of that is 150 Singapore Dollars per gallon. So it is very expensive." [M1_15]
	Hugh Potential to Reuse Waste	"Brazil has a huge potential. If we treated 10 percent of all the organic waste produced in this country, we would potentially produce all the insect meal needed to supply the planet! This is because we are that this huge agriculture or tropical country producing half a billion tons of organic waste which are reported - we are not even talking about what is not reported, which is probably double or triple that amount. If we used a 10 to 1 then we would use 5 million tons of insect meal. That would probably correspond to the global demand by 2050 worldwide." [Fe6, 95]
PROBLEMS IN THE FOOD	**Pressure for Alternative Sources of Protein (Substitute for Fishmeal)**	"I think it's only about 5 percent of the American populous who doesn't eat meat. 95 percent of Americans are eating meat. So you know, I think it's important to recognize just the realities of the world, which is chicken and pork and beef are delicious and people love to eat them. So as much as we can support the existing food system with what we're doing, I think that's another big part of our mission." [Fe5_119]
	Environmental Challenges in the Food Chain	Alfred Wegener Institute quotes: Plastics in the world's oceans becomes micro- / nanoplastics. It can now be traced to fish which is contaminated by the plastic. Accordingly, one needs an alternative. (Fe7)
OTHER ISSUES	**Do-It-Yourself-Trend**	"as the home-growing market is growing very fast anyway, and it is quite a trend to grow something at home. But there are not really options to do so." [Fo7, 13]
	Demand for Fertilizer	"Frass: we've been selling that to urban gardeners so as an organic fertilizer. And we're taking steps to be scaling up into larger agricultural markets but, for right now, we've had a lot of good traction in the urban consumer markets." [Fe5_22]

Appendix 11 Factors of Diffusion Dynamics in the Insect Economy

Table 24: Diffusion Dynamics in the Insect Economy

Diffusion Dynamics	Examples
Legal Hurdles/ Lack of Legislation	• “If there is "waste" somewhere, there is a certain legal regime behind it and cannot be used as a feed. Even if the products of these three subcategories are perfectly safe, from the moment that the concept of disposal prevails, then this product is by definition waste. It is unimportant how good the product is; it is no longer introduced into the feed chain. We are trying to change the laws.” [Fe7_20] • The other issue was that because it is a less developed country, there is less regulation on what to do with organic waste and how to treat it etc. So it was a lot more difficult to create a scalable solution for a partner companies because [5:36] here is very limited wastewater treatment than required.” [Fe2_87] • “Organic waste streams are kind of a silo. We see basically three levels of organic waste and there is only one material that should be called waste at this point the other ones are simple resources.: 1. Direct byproducts from the food system. If somebody wants to make perfect French Fries there is a lot of in perfect French Fries that is not being sold. We shouldn't call that waste. It's just underutilized organic material. What insects can kick in quickly. That is what we are focused on because we feel that the industry still needs to set up the safety and hygiene standards before it should start thinking about all the other stuff. 2. Is food that is produced but not eaten such a supermarket material simply because it is two days before due date. In a lot of countries, there is no infrastructure to do anything with that so, it goes to landfill or incineration plants. Thus, it is a total loss of nutrients. Still, it is not waste in my opinion, just again, it is an inefficiency in the food system. A perfect for insects. 3. The third group we call of waste. It includes slaughterhouse waste, manure, contaminated organic waste, organic post-consumer waste. It should be questioned whether this should be reused on a nutrient level because most of those project have better aggregations somewhere else. [Fe1_56]
Compatibility with Culture when introducing insects as food	• “There are a few reasons [why we focus on insects as feed and not an insect as food] for that: the thing is that there is a very big psychological gap for people to eat insects in Brazil. Brazilians might start eating insects in 30 years from now - at a large scale. That would be more of long-term orientation. Feed would be shorter to be established.” [Fe6, 95]
Compatibility of sustainability with “culture”	• “Here it’s a little bit more difficult because the people don’t have this awareness about sustainability and environment which is already quite high in the western countries.” [Fe11, 35]
Compatibility with Routines in industrial processes	• “Most of our customers, especially the agricultural space - the farmers - extremely conservative and risk averse scientists often because they […] have very little room for experimentation. But they're very data driven and they're very numbers driven in how they think about what they're going to be putting into their crops or into their animals.” [Fe5_61] • “When you are entering the feed market you have to align with the requirement of this market in terms of quality, quantity, and price. Actually when talking about quantity if we want to sell our product to a feed miller, a big feed miller, we cannot produce only one ton or even 10 tons a month, we have to produce at least, I would say 100 a month.” [Fe11, 114] • “Total production capacity of the insect space is small and we are taking a large part of it. Even though some people communicate that they produce more, we know for a fact that it is often not the case. A lot of products that you see in the market are from us. This doesn't help because the big future contracts

	that needed to change, if you look at the strategy of the big agriculture companies all of the big feed companies, high-end proteins are in the strategic area of the company risk profile. And because the availability is not secured und the prices can be very high, so either their core product is no longer competitive or can't be sold anymore. No, in those companies have another strategy which is the freedom to formulate. But they typically do not accept single source suppliers or risky suppliers. [We are] at this point an absolute risk if we would supply the biggest feed/ agricultural companies. Simply because there is no other suppler to address this risk and secondly because we are financially weak compared to many other companies. We need to establish a larger production base; we need to establish internationalization. We are beyond the start-up phase; we are a production company but we are not a solid international operating company. So there is another step to take. If we locate the insect industry in the future, I need to become a reliable food ingredient producer with multiple sources." [Fe1_83]
Prices and Economic viability to become a competitive food alternative	• "In the case of the United States is necessary because the cost of labor is so ridiculously high that insect protein becomes a premium food/ a delicacy. Cricket powder in United States is selling for $40 per pounds which is $90 per kilo. It is hard for me to say that you are charging people at $90 per kilo for protein powder made of insects and on the other hand saying that insects use less resources than meat. That doesn't make sense. If you're honest about that they are using less resources, then you cannot charge such high prices. The truth is insects in theory are more sustainable when in practice business is trying to efficiently farm insects like in the cattle industry past 100 years and agricultural subsidies and Innovation before it got replaced with the efficiencies that exists." [Fo1_116] • "The African market is excluded for now as the products are not economical enough to export there" [Fo8, 7] • "You cannot be too far off. If the cheapest ingredient is far off the product you are offering then you won't sell: if your product is 3 times or 4 times more expensive than kilograms will be sold but not tones - especially mean in special especially not a thousand times but if you are reasonably close then there are many markers that will see you as a competitiveness driver." [Fe1_65]
Legal hurdles for exportation	• „In order to export insects from Israel the authorities are asking us to about the regulations in the target market. In Africa, Asia and Central America there is no local regulation in regards to the import of insects. So, it is impossible for us to export to these markets at this point in time. So, even though there is high demand in these countries we are not allowed to export into any of these countries or continents." [Fo2_77]
Over-engineering the emerging industry	• "we're over engineering this completely because we're thinking like engineers, waste management engineers. […] To me that's the dumbest thing you can do when you have a black soldier fly that would tear it down themselves for free. If you look at [company x], for example. They just announced a $70 million funding round and they've realized that labor is what's killing them. So they're doing everything robotic. I'm very interested to know what their output tonnage is and what their capital cost is. It's going to be more than $2,000 to $3,000 per output ton of capital per … when I say this number … so [company y] is producing 7,000 tons of meal for a $15 million to $25 million investment. So that's $3,500 of investment to produce one ton per year. Does that make sense? That's how I look at that. So if I buy an acre of land at $2,000 and I can produce more than one ton of soy meal then my CAPEX [Capital Expenditure] for my soy is cheaper. For [us], we are projecting that we're able to produce one ton of dry insect matter for $1,000 and the reason is that we don't have all of the capital expenditure that comes with this factory." [W1_32]

EIDESSTATTLICHE ERKLÄRUNG

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