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Hiam Serhan, Gwenola Yannou-Le Bris

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The engineering of food with sustainable development goals: policies, curriculums, business models, and practices

Serhan, H., Yannou-Le Bris, G.

UMR GENIAL, AgroParisTech. INRA, Université Paris-Saclay, 91300 Massy, France

Abstract

The environmental, nutritional, and socio-economic issues in the globalised agro-industrial food system are at the center of political agendas, reform programmes, and sustainable curriculums in higher education institutions to accelerate the sustainability transition of food sociotechnical systems. Despite the societal importance of these issues there is little proposals aiming to address sustainable development goals in food science and engineering curriculums. However, promoting project-based learning by students on how to develop eco-designed business models and eco-innovated food products seem to be an essential lever for the sustainability transition. This paper describes how a consortium of French agri-food engineering colleges implemented sustainable development goals via the governmental Idefi-EcoTrophelia programme. Through two cases, we show how the students used engineering and managerial knowledge to eco-design business models and to develop entrepreneurial capabilities to establish green ventures to commercialise their innovation. To analyse these projects we propose a sustainable business model canvas that describes the processes through which food eco-innovations were developed and transferred from the research institutions to industries and consumers. This model facilitates understanding how the sustainable development goals transform food sociotechnical systems to create societal values.,

1. Introduction

Over the past few decades, the environmental issues in the globalised agro-industrial food system – that is, the ways in which institutions, agriculture and farmers, food industries, and consumers organise their practices to produce, prepare, and consume food products – have raised concerns about their long-term sustainability (Caron et al. 2018; FAO 2015, 2018). These concerns comprise environmental issues (e.g., air pollution, species diversity, ecosystem integrity, increased food miles,¹ intensive livestock production), socioeconomic issues (rural impoverishment and vulnerability of small farmers), and nutritional and health issues associated with inappropriate food consumption and unhealthy diets.

Today, the impacts of these problems and the ways to address them are at the centre of the political agenda (e.g., the 2030 United Nations Agenda for Sustainable Development, 2017), reform programmes (Reform of the Committee on World Food Security 2009), and future goals and scenarios (OECD 2015, 2016). They call for an ‘ecological transition’ through innovation that develops and diffuses clean technologies and initiates broader changes in sociotechnical systems (Geels and Schot 2007). These changes aim to improve the socioeconomic, nutritional, and environmental impacts of the world’s dominant industrial food system and transform consumers’ behaviour and even the meaning of what they are eating (Yannou-LeBris et al. 2019; FAO 2015).

Initiating an environmental transition is motivating actors to eco-innovate supply chains (Egilmez et al. 2014), improve the lifecycle environmental impacts of food products by reducing the social and production costs related to conventional agriculture and food processing. Nonetheless, implementing these sustainable policies in strategic management (Miah et al. 2017) and business models remains difficult (Lüdeke-Freund 2013). In the agri-food industries, implementation is slow because of a shortage of capabilities and competencies necessary to implement the sustainable development goals (SDGs) operationally. Reengineering food products with eco-innovation practices will necessitate

including SDGs in the activities, structure, and governance of business models (BM) (Bolton and Hannon 2016).

To develop these engineering capabilities and competencies, the European institutions of higher education are introducing new curriculums to increase the competences of teachers and students to better understand the systemic nature of eco-innovation and facilitate its implementation in projects and business activities (Ramisio et al. 2019; Sammalisto et al. 2016; Lozano et al. 2014).

Despite the increased research on the broad range of issues regarding sustainable engineering (Rossi et al. 2019; Moon 2016; Rahimifard and Clegg 2008; Bakker et al. 2009), further studies are needed to augment our knowledge about the systemic nature of eco-innovation and the importance of business model innovation. They can provide a better understanding of how sustainable food products can be designed and delivered to consumers. Rahimifard and Trollman (2018) underscore the urgent need to increase engineering capabilities to integrate the underlying principles of SDGs into engineering education and how SDGs are implemented in practice. We respond to this call by examining a curriculum called Idefi-EcoTrophelia, introduced by the French government that funded institutions of higher education to train agricultural and food engineers and designers to eco-design BMs to create food eco-innovations and introduce them in the market.

Business model innovation (BMI) is increasingly recognised as a key driver to deliver greater social and environmental sustainability in systems of industrial activity (Lüdeke-Freund 2013). Despite the growing literature on business model theories (Stubbs and Cocklin 2008) and BMI drivers and barriers (Andreini and Bettinelli 2017), no case studies are available that examine how SDGs can be embedded in higher education programmes to teach students how to create BMs on delivering eco-innovated food solutions to agri-food industries and the market.

The main objective of this research is to show that eco-designing food is a complex systemic approach, through which regulations, consumers wants and desire, standards and industrial resources and capabilities contribute to the formulation of a single product. To be successful, eco-innovators must manage the interaction of policies and negative externalities in the incumbent food regime. For this reason, new training techniques, capabilities, and competencies need to be developed in order to create ecologically beneficial food niches that not only meet the unmet consumer demand but also satisfy broader societal wants and needs. Through two case studies, we identify the processes used by two teams of French engineering students to align business strategies, food policies, and consumer needs so as to eco-design food BMs and established environmentally aware new firms. We explore how these two entrepreneurial ventures introduced economically viable and nutritious products with smaller environmental impacts and respected the social dignity of their employees and others affected by their innovations.

This paper increases our knowledge about sustainable food engineering practices in two ways. First, it describes the curriculum of Idefi-EcoTrophelia to diffuse eco-innovation practices into educational programmes. Second, it highlights the ways in which the engineering students involved in this programme developed not only the required engineering capabilities to eco-design and innovate new food products but also entrepreneurial competencies and managerial capabilities to sense and seize opportunities for developing new BMs.

The paper is structured as follows. In Section 2, we provide an overview of business model literature with a particular emphasis on the importance of dynamic capabilities to analyse sustainable transition and the societal impacts of its innovation in activities, structure, and governance. Section 3 describes the Idefi-EcoTrophelia program, goals, and tools. This section presents the process through which the various institutions collaborated to introduce eco-innovation into their teaching methods. We also

describe the sustainable BMI framework that was created to analyse the eco-design practices used in the students' projects. In Section 4, we present and analyse two of these projects to illustrate how the student engineers translated some of the SDGs into eco-designed BMs and created economically successful, socially inclusive, and environmentally friendly food products.

2. The importance of business model innovation for sustainable transition

2.1. Business models and business model innovation

A business model is a conceptual tool that describes how a firm creates and delivers value to its customers, partners, and vendors (Teece 2018; Osterwalder and Pigneur 2010). BMs connect three interdependent elements (Amit and Zott 2012). The first element encompasses the selected activities to be performed. This refers to the 'content' of a firm's activity system. The second element consists of the ways in which these activities are linked and sequenced. This describes the 'structure' or 'how' activities are performed. The third element is 'governance,' namely, 'who' performs the activities, and with which skills, and the resources that can compete in their target market. It is possible to distinguish two different conceptualisations of a business model. The first is static, in that it refers to a structural representation or a replicable configuration that confines the value of a firm's core activity to a specific set of goals and practices (Demil and Lecoq 2010). The second conceptualisation is dynamic, as it focuses on the dynamic capabilities and competencies (Teece 2018; Helfat and Martin 2015) that an organisation develops and mobilises to facilitate the evolution of its business model from a static pattern to a set of dynamic and interdependent actors and opportunities.

Dynamic capabilities are the skills that organisations develop to sense and seize new business opportunities. In the food sector, they include understanding market and social requirements, creating new knowledge, recruiting responsible partners, and mobilising resources to eco-design and eco-innovate sustainable agricultural and agro-industrial practices (Yannou-LeBris and Ferrandi 2016). Eco-design or eco-efficiency means considering the environmental impacts of a product in the early stages of its life cycle (Kendall and Spang 2019). Eco-innovation consists of integrating circular-economy principles into both social and environmental innovation processes and being mindful of waste and end-of-life recycling (Ademe 2018); in a circular economy, the food waste of one process is reused as a resource in another process. Eco-innovation transcends traditional eco-efficiency, which concerns a reduction in resource inputs, including energy, as well as in waste and emissions and at least one of the four dimensions of sustainable development in food: economic, environmental, social, and nutritional (Yannou-LeBris et al. 2019; FAO 2014).

In both the static and dynamic perspectives, value creation is at the heart of every business model. Value represents the aspects of a product or service for which customers are willing to pay (Drucker 2002). In terms of sustainable performance, this refers to the relevance of a business model value proposition, which, in turn depends on the relevance of the knowledge value chain in an activity system. This refers to the sequence of cognitive activities (Martins, Rindova, and Greenbaum 2015) in which actors transform data (raw facts, requirements, trends, environmental pressure) into information (data with meaning). This is transformed into knowledge (information that can be operationalised in a specific context) and finally into practical wisdom (Nonaka and Toyama 2008), which is the ability to use the knowledge to achieve the desired goals (Yannou-LeBris and Serhan 2018; Ermine 2013; Powell 2001). This knowledge management process is intended to achieve BMI by involving a company's business model elements – activities, structure, and governance – in a sustainable transition by eco-innovating solutions (Teece and Linden 2017; Birkinshaw and Ansari 2015; Wu, Guo, and Shi 2013; Malhotra 2002).

2.2. Business model innovation for food systems' transition to sustainability

BMI generally refers to the search by companies for new business logics and new ways to create and capture value for their customers, partners, and suppliers (Amit and Zott 2012; Aspara et al. 2013; Casadesus-Masanell and Zhu 2013). It offers the potential to provoke sustainable changes through the development and mobilisation of organisational and managerial dynamic capabilities (Helfat and Martin 2015; Teece 2018).

A transition concept – which refers to a gradual and reflexive trajectory of change from one state of production, processing, and consumption to another (Lachman 2013) – brings into focus the new state to be achieved, the path towards a new state, the transition problems including path dependencies and lock-in effects in the system to be changed, and the wide range of internal and external developments that may shape the outcome (El Bilali 2018; Kemp 1994).

The growing body of literature on sustainability transition concerns the long-term transformation towards sustainability of sociotechnical systems in various domains, such as energy and water supply, transportation, and agricultural and food systems (Markard, Raven, and Truffer 2012; Geels and Schot 2007; Meynard et al. 2016; Smith, Vos, and Grin 2010). In a parallel strand of research, BMs and sustainable development focus explicitly at the firm level (Bolton and Hannon 2016) to examine how the development and implementation of novel BMs can create and capture value from sustainable innovations (Boons and Lüdeke-Freund 2013). In recent years, there has been growing interest in how these two strands of research might be synthesised to offer insights into how BMI could act as a catalyst for systemwide sustainability transitions (Bolton and Hannon 2016; Boons and Lüdeke-Freund 2013; Loorbach et al. 2010). Thus, through its value-creating logic, a business model can be viewed as a strategic model to analyse sustainable transition and the societal impacts of its innovation in activities, structure, and governance (Amit and Zott 2012; Beattie and Smith 2013; Bocken et al. 2014). Using the BMI pattern to analyse food-eco-innovation projects in French engineering higher education institutions enables us to illustrate the competencies and dynamic capabilities needed to achieve a transition from ‘traditional innovation for economic productivity and market share’ to ‘green innovations grounded on various SDGs’ (Kemp 2010; Kemp, Rip, and Schot 2001).

Agri-food systems transition management is a programme, model, and set of tools or instruments to support the co-evolution of three types of sociotechnical systems landscapes, regimes, and niches. A sociotechnical system is a collection of stakeholders, their networks, practices, and knowledge; the technologies they use; their collective representations; and the standards and rules they adopt (Kemp, Loorbach, and Rotmans 2007; Lachman 2013; Rip and Kemp 1998).

The landscape encompasses the trends and global pressures, such as the growing population, food security, public food policies, ecosystem degradation, resources depletion, and health problems related to food within which action will be taken (FAO 2018).

The sociotechnical regime comprises the network of dominant actors, formal and informal rules, technologies, and consumption behaviour that form and maintain the globalised agro-industrial food system (Meynard et al. 2016).

Niches are spaces (e.g., sustainable or green start-ups, R&D laboratories for eco-design, farmers market niches, experimental and demonstration food projects, food labs) where innovative activities take place as alternatives to the policies and practices of the dominant regime and landscape (Smith 2007). The landscape constitutes a source of pressure for regime change and opportunities for niche development (Smith, Vos, and Grin 2010). Societal change come about through ‘transition pathways’ (Geels and Schot 2007) formed through interaction, alignment, or co-evolution of objectives and practices between all relevant actors at different societal levels, such as the food policies and institutions, universities, agri-food industries, supply chain participants, and consumers.

The complexity of a food system transition – due to the fixed infrastructure and rigid policies at the landscape level, the various actors governing the dominant agro-industrial regime, and the multilevel processes involved in the change programme – underscores the necessity of studying specific programmes that have deployed SDGs to accelerate transition in the food systems, i.e. interactions within and between the three sociotechnical systems, landscape, regime and niches.

In this research, we present the EcoTrophelia innovation programme as a transition pathway that enabled French engineering colleges and students to develop hands-on projects and transfer technology from universities to industries and consumers.

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3. Teaching sustainability at European and French institutions of higher education: curriculums and skills

European institutions of higher education have achieved significant progress in meeting SDGs (Lozano et al. 2014; Ramisio et al. 2019). This progress has been attained by undertaking various initiatives, programmes, and research. For example, the Technical University of Catalonia has developed a green curriculum including the implementation of various environmental projects (Capdevila, Bruno, and Jofre 2002). Swedish institutions of higher education incorporated sustainability learning, knowledge, and actions into their curriculum (Sammalisto et al. 2016). Other researchers analysed the commitments and implementation approaches of environmental management systems at institutions of higher education internationally (Lozano et al. 2013), such as the practical education programmes and critical success factors used to implement environmental management systems in higher education institutions (Disterheft et al. 2015), and the circumstances in which key skills for sustainable development in higher education are developed (Barth et al. 2007).

The results of these studies suggest that higher education is a particularly important vehicle for teaching sustainability and developing the skills to address sustainable development issues. Despite these general efforts, little study has been conducted on how to implement food sustainability research and praxis programmes in higher education and how teachers and students develop skills and co-evolve to design and implement eco-innovated BMs in real-world projects. Our research addresses this gap by describing the new curriculum of the French government (Idefi-EcoTrophelia) to assist students in developing new entrepreneurial capabilities and skills through creating innovative food products. We explain how teachers and students in this programme needed to navigate the complexities of food business system eco-design, eco-innovate, and attempt to introduce their new products in established food industries and markets.

3.1. The ANR (agence nationale de la recherche)-Idefi-Eco Trophelia challenge

3.1.1. Idefi-Ecotrophelia initiative to contribute to food systems' sustainable transition

In 2012, the Idefi-EcoTrophelia project was selected by the French Department of Agriculture as one of the winners in a call for 'Innovative Training Excellence Initiative' (Idefi) projects. Thirteen institutions of higher education specialised in agricultural and food engineering and designing² took part in this project to contribute to two goals. First, to raise the consciousness of engineers and

designers about their responsibilities in the reengineering of food systems and their mission in the trajectory towards environmental transition.

Second, to create teams of professors, students, and industrial partners aimed at conceptualising and completing sustainable food innovation projects within an academic year by addressing one or more of the SDGs.

The EcoTrophelia projects aimed to achieve at least one of the following goals regarding sustainable food development: making it economically efficient with affordable prices and physical access, making it environmentally friendly, making it socially inclusive, and making it sufficiently nutritious and healthy. These four goals were used to develop criteria to be considered during the development of the projects as well as by the jury at the annual France EcoTrophelia competition to evaluate them. These criteria included the sustainability of raw materials and the suppliers selected, the technologies used, relevance of the value proposition and the market segment targeted, reduction in the environmental footprint, reduction in the use of water and energy, recycling of wastes, marketing tools and distribution methods, social inclusiveness, and the nutritional impact were the main characteristics to be considered in processes for attaining sustainable food through reengineering. The projects selected by the French jury were then entered into the European EcoTrophelia competition.

3.1.2. Food reengineering projects: principles and programmes

The implementation of the Idefi programme and the achievement of the EcoTrophelia projects relied on two principles:

The first principle consisted of teaching and proposing tutorials about different concepts in the literature to support the training of 'sustainability engineers,' i.e., have the skills to create and develop sustainable products and BMs. This teaching programme included concepts such as sustainable design and sustainable innovation (Charter and Clark 2007), designing cradle-to-cradle products (Bakker et al. 2009), circular economic patterns (Ademe 2013), lifecycle assessment methods (ISO 14040; Wimmer, Züst, and Lee 2004), analysis and management of threats and opportunities (Porter 1985), management of environmental quality (Carayannis, Sindakis, and Walter 2015; Krishna and Manickam 2017), BMI for sustainability (Evans et al. 2017; Lüdeke-Freund 2016; Casadesus-Masanell 2011; Chesbrough 2010; Demil et al. 2015), partnership theory (Levin and Tadelis 2002; Sachs and Rühli 2013), and sustainable marketing and consumers' behaviour (Charter 2017; Jellil, Woolley, and Rahimifard 2017). These concepts were intended to make the engineering students aware of the nature and role of resources, knowledge, entrepreneurships and partnerships, and societal needs in the dynamics of food innovation.

The second principle represents the empirical part of the programme. It consists of integrating the sustainable development principles and indicators at each stage of the project. These included sessions for brainstorming and design considerations, knowledge management to identify, seize, and obtain market opportunities, definitions of product technical specifications, trial-and-error experimentation with prototypes developed in food labs, and market testing to evaluate product acceptance.

Each EcoTrophelia project was developed with the objective of becoming an entrepreneurial venture

4. Research methodology

The core of the research reported here is the result of an analysis of 11 EcoTrophelia projects presented at French and European competitions between 2009 and 2016. The data used to illustrate eco-innovation projects derive from the documents that the students prepared during the product development process, which took an academic year. Each document was 100 to 150 pages in length and provided detailed scientific and technical information. Further, it discussed the partners that the students mobilised to design and operationalise their BMs.

The two case studies analysed here were selected for three reasons.

First, they address global societal problems. When these projects were submitted to EcoTrophelia French and European competitions (2009 for VitaPlus and 2013 for Ici&Là), the concepts and practices mobilised were highly innovative and currently absent from French food markets.

Second, these projects mobilise different sustainability criteria or dimensions recommended at international, European, and French institutions policies as sustainability dimensions to achieve in food innovation (Credoc 2008; OECD 2009; PNNS 2001).

Third, because the term sustainability is so diverse and multi-faceted, our objective is not to compare the two projects but, rather, to show the various strategies that the students employed to create sustainable BMs and food products.

To illustrate in a simple and descriptive way the various and complex processes used by the students to create the 11 projects, we created a generic sustainable business model framework to analyse the structure and nature of eco-innovations created in each project (Figure 1). This framework represents the processes through which the teams eco-designed and adjusted their choices during the development of their projects. Because of the systemic and multi-faceted nature of food eco-design, the interest of using a BM framework relates to its broader and more interdisciplinary than many other food eco-innovation approaches, such as industrial ecology (Kendall and Spang 2019), life-cycle assessment (Ademe 2019), and supply chain eco-innovation (Egilmez et al. 2014) that tend to focus mainly on the environmental impacts of food innovation processes. The business model canvas we propose allows capturing the big picture questions that can inform the search, creativity, development and marketing processes that occur in food eco-innovation and should be present in training students on how to translate and implement SDG in practice.

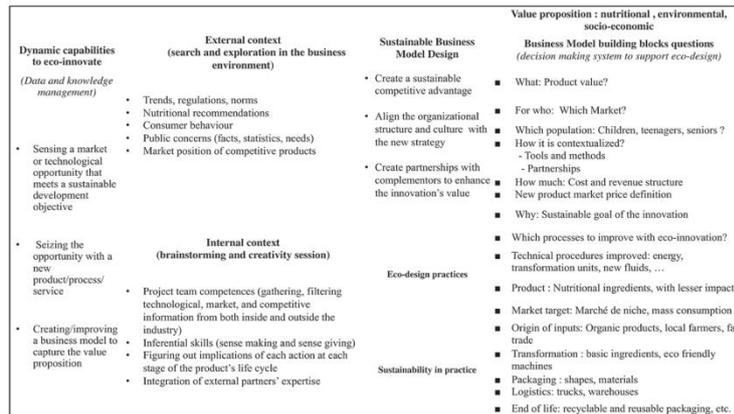


Figure 1. The business model framework for food eco-innovation

This model can also be used as a food eco-innovation roadmap as it allows complex eco-innovation dynamics to be tried and then analysed, thereby providing a better understanding of how sociotechnical systems interact and co-evolve to create sustainable values.

Based upon the business model structure and dynamics defined by Amit and Zott (2012), the analysis of these 11 projects enabled us to identify four key eco-innovations that characterise the design components of a company's business model. These innovations explain how BMI for sustainability can create value and mutual benefits for all the actors involved in or affected by innovation.

4.1. Key innovations in the value and business model design elements

4.1.1. Innovation in product value

The BMs for the 11 projects presented at the EcoTrophelia France competitions between 2009 and 2017 were oriented towards at least one of the following strategies: 'achieving health through food,' 'repurposing by-products or co-products to avoid food waste and losses,' 'making BMI socially embedded,' and 'finding protein sources to substitute meat consumption with vegetables.' Using these strategies, the teams' objectives were to address the following SDGs:

SDG2: 'End hunger, achieve food security and improved nutrition, and promote agriculture'

SDG6: 'Sustainable water management'

SDG7: 'Use of affordable and clean energy sources'

SDG9: 'Industry, innovation, and infrastructure'

SDG11: 'Sustainable cities and communities'

SDG14: 'Preserve and sustainably exploit the sea water'

SDG15: 'Preserve terrestrial ecosystems'

4.1.2. Innovation in the content of business models, or 'what new sustainable activities can Eco-innovation create'?

BMI can occur by adding a novel sustainable activity to a company's activities. For example, one team aimed to repurpose the whey produced in making cheese. Whey is rich in nutrients but normally treated as waste and, as such, is highly polluting. To accomplish this, the team established a partnership with a dairy firm searching for new ways to reduce the impacts of its practices on the

environment. The food innovation created was a dietary supplement for the elderly in the form of pills (Prolactésir project presented at EcoTrophelia France 2014). Through this project, the engineers added a new activity and a new product to the firm's portfolio without undermining its existing activity. This partnership created economic and environmental values in the firm's activities and permitted the dairy firm to claim that it was contributing to SDG 17 ('Partnerships to realise sustainable goals').

4.1.3. Innovation in the structure of business models, or 'how can BMI develop responsible relationships'?

Innovation in the structure of BMs focuses on how strategic processes are coordinated so as to enhance one or more aspects of sustainability (e.g., reducing energy and water consumption, chemical inputs, carbon footprint, cost savings). For example, the goal of one team (PannIno Project-EcoTrophelia France, 2016) was to reduce the carbon footprint of the bread making industry within the framework of a circular economy. The activities chosen to address this challenge were structured to transform bread crusts that are normally discarded as waste in the bread industry into gnocchi.

The analysis of the project shows that the goal of a 'low carbon footprint' was achieved through the close linkages between the strategic activities of the firm, including the sourcing raw material (bread crusts) from local bakeries, integration of the transformation process into a partner firm's plant, and the distribution of the product at local and regional supermarkets, thereby reducing the transportation impacts. By repurposing food waste and rethinking how the activities are linked, this project contributed to meeting SDG12 ('Sustainable consumption and production') and SDG13 ('Alternative actions to address the impacts of climate change').

4.1.4. Innovation in business model governance, or 'who will perform the activities to increase the sustainable impact of the product'?

In 2016, engineers at the ESIROI engineering school on Réunion Island were designing a nutritious and eco-friendly solution for hospital patients who have difficulty swallowing food. The eco-design of the business model was guided by three goals. First, patients' swallowing problems needed to be addressed. Second, the number of hospital meals imported from France needed to be reduced, thereby reducing the environmental footprint caused by transportation. Third, the hospital needed to reduce its losses due to discarding inappropriate meals given to patients with difficulty in swallowing or those that were rejected as unappetising. The business model analysis of Mixi'Mousse, which was created to achieve these goals, shows that the socioeconomic value of the innovation is related to its co-creation and by involving a variety of different partners: the hospital, local suppliers of the raw materials used in the new recipes (rice, meat, fish, vegetables), the hospital dietician, and the startup created by the engineers. All these partners participated in the new activity and in each process-improvement decision. The complementarities of these partners (e.g., resources, experience, skills) added to the nutritional, social, and environmental value of the project. This innovation contributed to achieving SDG3 ('Good health and well-being for all').

5. The two case studies from the EcoTrophelia project

In this section, we use two case studies to illustrate how the business model components translated into operational practice and sustainable food innovations.

5.1. Ici&Là project: Isara Lyon, EcoTrophelia Europe 2013

In 2012, nine engineers from the food science engineering school Isara Lyon, decided to address meat production issues by proposing a vegetarian burger made of lentils and grains – such as wheat and rice

– called Ici&Là, particularly the PDO (protected designation of origin) green lentil grown in Puy-en-Velay.

5.1.1. Market threats and opportunities

Competitors. The market study undertaken by the engineers revealed the presence of various burgers competing as meat substitutes, made from ingredients such as vegetables, soy (soybeans, tofu), and grains (seitan, wheat gluten). They did not identify a product based on a blend of lentils and other legumes that resembled the one that they envisioned.

Demand. To confirm that a market for their product existed, they conducted a market survey of 341 consumers in different age groups. The survey aimed to identify what their target consumers were currently consuming, whether they would be interested in trying this new vegetarian burger, and how much they would be willing to pay for it. Their survey considered five key criteria in eco-designing their business model: consumer enjoyment, nutrition content of the ingredients, environmental impacts, convenience, and ethical values to be met in the entire project.

5.1.2. The Eco-design strategy

To frame the eco-design choices to be integrated into the project and to address the environmental impacts of the new product over its entire lifecycle, the engineers applied eco-design tools such as the ‘simplified and qualitative evaluation of lifecycle assessment’ method and the Eco-design Pilot Version 2.

- Choice of raw materials: why the Puy-de-Velay lentils and other legumes?

“Lentils are among most consumed legumes because of their levels of protein and iron. When they are combined with grains such as rice, their nutritional value is increased. This combination rebalances the respective contribution of two essential amino acids: lysine (lentils have a high level) and methionine (rice has a high level).”

- Consumer enjoyment

To increase the organoleptic value of the innovation, the engineers collaborated with Master Chef François Gagnaire (a chef with three Michelin stars): “The advice of Chef Gagnaire helped us improve its gastronomical value according to the French cultural norms (taste, texture, and shape of the burgers).”

- Economic and social benefits

To increase the socioeconomic value of the product, the engineers relied upon a number of studies. We illustrate this with quotations from some of these studies:

“The largest amount of PDO lentils is produced by the association La Lentille Verte du Puy (Green Lentils of Puy-en-Velay), whose members have struggled for decades to find customers and good prices for their organic products.” “By exploiting this variety of lentils, we develop the regional economy and preserve traditional agricultural practices. Moreover, this will improve the financial conditions for other lentil producers in the region. According to the Center for the Rural Economy of Haute-Loire, PDO lentils from Puy-en-Velay earn income for 900 producers of 305 euros per month (more than 10% to 15% of average farm income). In this region, one hectare of lentils earns 10% to 15% more than a hectare of wheat.”

- Environmental benefits

“Because of this lentil production, nitrogen, phosphorus, and potassium fertilizers are prohibited, as is irrigation. The particular climate and geography of Puy-en-Velay gives the green lentil its nutritional value. In summer, drought creates severe water stress, preventing the ripeness of the lentils. Thus, they have a thinner skin, which increases its permeability during cooking, reduces its amount of starch, and creates its culinary characteristics, such as quick cooking and delicate flavor.”

- Production and processing

To reduce the environmental impact of Ici&Là, several eco-innovation practices were implemented in the production process. ‘We decided to implement the transformation plant in Puy-en-Velay to minimise the transportation costs and carbon footprint of the raw material supply.’ ‘The “double walled cutter” of the machine used for cooking and grinding the lentils was replaced by two large pans and one simple walled cutter. This enabled production at a low temperature. Thus, the cooling line has been eliminated, and the time for freezing was decreased.’

- Distribution methods and storage

To reduce food spoilage and losses during distribution and storage, the engineers froze the burgers in family packs consisting of individual packages designed by ESEPAC4 and ‘2PourEmballer.’⁵ Transportation to supermarkets was subcontracted to STEF-TFE, whose practices comply with European Union environmental standards.

- Consumption

Ici&Là burgers are easy to prepare, as they do not need to thaw and require only six minutes of frying.

Because of these eco-design practices, Ici&Là was presented in the competition as ‘le boucher vert’ (the green butcher) and won the EcoTrophelia Europe competition prize in 2013. In 2017, the startup changed its name to Hari&Co. (haricot means ‘bean’) and introduced more organic meat alternatives made of chickpeas and other legumes. In 2017, they served 750,000 meals in the institutional catering market. Its products are currently stocked by 600 stores specialising in organic products.

The eco-designed business model of the Ici&Là project is summarised in Figure 2.

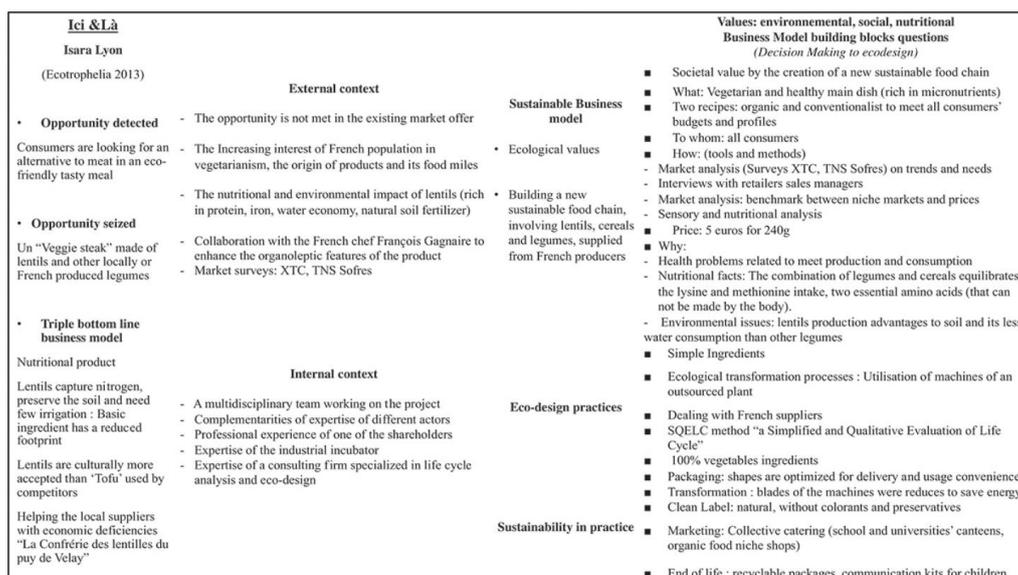


Figure 2. The eco-designed business model and eco-innovation practices of the Ici&Là project

5.2. VitaPlus: AgroParisTech-EcoTrophelia France, 2009

The VitaPlus innovation aimed to contribute to achieving SDG3 ('Good health and well-being for all and for all ages'). To do so, the engineers at AgroParisTech relied upon the results of a market study, studies by experts at the Food and Agriculture Organisation (FAO) who have linked the prevention of some chronic diseases, such as some cancers, diabetes, osteoporosis, obesity, and cardiovascular diseases to nutrition (Nishida et al. 2007), and the French Nutrition and Health Programme (PNNS),⁶ whose primary objective is to improve public health through nutrition policies.

Their market study revealed that

"For decades, the population of 'active seniors' from 50 to 70 years old has experienced a flourishing of service offerings, such as banking, insurance, and travel facilities, but they did not get the attention they deserve from the food industry, even though food can prevent several health issues related to aging. 72% of this population believe that the prevention of health issues means paying attention to what they eat (Credoc 2008)."

The first idea of the engineers was to create a 'ready-made meal' solution that could prevent major nutrition-related chronic diseases among active seniors.

5.2.1. Development of the vitaplus concept

The engineers had two challenges:

"First, to take into consideration the scientific basis of the relationship between the major nutrition-related chronic diseases among seniors and the ingredients that could be added to the product. Second, to combine the needs of the target segment, the consumption trends, and the seniors' needs to determine which customers and societal problems they aimed to solve."

To address this challenge, several exploration and feasibility studies and analyses were conducted to strengthen the VitaPlus concept. The VitaPlus nutritional, social, and environmental aspects of sustainability are summarised in their business model as depicted in Figure 3.

- Demographic and economic importance of active seniors

The students state: *'Active seniors represent one-fourth of France's consumers of "ready-made meals"' (Datamonitor, 2005).*

- Potential competitors

The market study found that *"since 2000, the innovations for active seniors were mainly based upon making the packaging easy to use, enriching products with phytosterols aimed at lowering cholesterol levels, and enriching products with collagen and glucosamine for seniors suffering from joint problems."*

- The seniors' needs survey

To measure the attractiveness of the VitaPlus concept, the students conducted a survey questionnaire of 205 active seniors in various socio-professional categories regarding their consumption behaviour and the health issues that they wanted to prevent or ameliorate with food.

'This survey identified three frequently mentioned health concerns: cardiovascular disease, age-related macular degeneration, and joint flexibility.' To increase the relevance of their innovation

value ‘health through food,’ the engineers add to their recipes ‘active ingredients,’ that is, biologically active components that are effective for particular health issues.

- Selection of active ingredients: the value added of the innovation

The selection of these ingredients required the help of external sources: ‘*We collaborated with Diana Naturals, a supplier specialising in natural ingredients, and we selected three natural active ingredients to design three recipes.*’

1. *Memory and vision.* Portions of *pavé de saumon* (salmon filet with a *beurre blanc* sauce) were created from salmon and vegetables and with the addition of active ingredients known to be effective in preventing age-related eye and cognitive disorders:
 - Cherry acerola powder, which provides Vitamin C that works together with Vitamins A and E.
 - Carrot concentrate, rich in carotene, which is a precursor of Vitamin A known for its antioxidant properties that slow ageing.
 - Salmon powder, which provides Omega 3 and, more particularly, DHA (Docosahexaenoic acid), a fatty acid known for its structural and functional role in protecting the retina.
2. *Cardiovascular diseases.* Portions of *tagliatelles au cabillaud* (codfish with tagliatelli) are made up of cod, pasta, and vegetables. It was enriched with HealSea®, a fucus powder recognised for its role in reducing the formation of arthritis plaque, which can cause cardiovascular disease.
3. *Joint flexibility.* Portions of *mijoté de boeuf au cassis* (beef stew with black currants) were enriched with Chondractiv, active ingredient made from chicken cartilage powder. Chondractiv® contains collagen type II and chondroitin sulphate, which are both considered effective in reducing inflammation and joint pain.

- Eco-designing packaging and labelling

The packaging was designed by Strate Ecole de Design. It is a lunch box with two compartments or a ‘nomadic bag’ adopted for several sustainability reasons:

“The folded axis in the middle of the box separates the two components of the meal and avoids food waste. It has two handles to facilitate gripping and avoid burns to the hand. The meals can be eaten directly in the package or poured onto a plate. The box is made of PET (polyethylene terephthalate), a microwavable, impact-resistant, and recyclable material.”

For text printed on the box, they used ultraviolet flexo ink, which is environmentally clean, safe for consumers, consumes less energy, and allows very high-quality printing.

- The VitaPlus innovation: from food labs to industrial production

The challenge for the students was to scale up recipes to the industrial level, where the technology, pace of production, and quality control requirements, such as expiration dates, costs, energy and water conservation, and recycling of waste, require different resources, partners, and significantly more financial resources. For financial reasons, the engineers contracted the production of VitaPlus to an established producer of ready-made meals. This decision decreased their production costs and eliminated their need for a large capital investment and allowed them to benefit from the established firm’s customers, consumers, and brand image.

The eco-designed business model of Vitaplus is summarised in Figure 3.



Figure 3. The eco-design and eco-innovation practices of the VitaPlus project

6. Discussion

To achieve the SDGs related to food systems, the primary goal of EcoTrophelia projects was to make food production and consumption more valuable and lead a shift away from the production of products unhealthy for consumers, the environment, and wasteful of natural resources.

The practices mobilised and the relationships created in the projects' development processes show that eco-innovation in food is a learning process that can provide lessons beyond just creating new products. Although the literature generally presents food eco-innovation through a lifecycle analysis perspective of the product to be developed (Ademe 2018; Laslu and Mustatea ; Nee, Song, and Ong 2013), the business model pattern followed by the engineers to eco-innovate food products as illustrated in these case studies shows that the design and operationalisation of projects included not only their environmental impact but also their economic viability and their social impacts and acceptability. From business model design to experimentation in food labs (VitaPlus) or in the market (Ici&Là), the two case studies demonstrate that a sustainably innovated business model can be created within a knowledge value chain management process. Multidisciplinary and co-innovation between various partners are key elements to develop this knowledge. These are the essential basis for eco-innovation as they permit the confrontation, consideration, evaluation and implementation of new knowledge and knowhow synchronously between these partners.

This knowledge management process required organisational and managerial dynamic skills to collect data (facts, needs, and trends) transform them into information and then knowledge, to create the sustainable value through developing their product. This chain is crucial for sustainable business model innovation and a transition to sustainability, as it links the recommendations for food policies with the negative externalities of the dominant agro-industrial regime to develop green niches (Smith 2007). They created new structures linking different actors from a variety of organisations from inside and outside the food sector, thereby designing business models with content, structure, and governance that were mutually reinforcing.

The analysis of these case studies shows that the eco-designed business model enables the combination of previously unrelated knowledge and the needs of various stakeholders who worked and innovated separately (for example, farmers, dieticians, chefs, industries, and bakeries). This led to sustainable-coupled innovations (Meynard et al. 2016), which are meant to increase the sustainability of agriculture, food processing, distribution systems, and consumption collectively by deriving benefits from their interconnections. In this respect, an eco-innovated business model can be viewed as a 'coupling artefact' that involves various fields and knowledge that

emerges during the design and development at each project stage to create feasible scenarios and global societal solutions.

The evaluation of eco-innovated food projects and their market success scenarios were considered on the basis of their meeting three main criteria: 1) the consumers' acceptability of the product's organoleptic quality; 2) the marketing promise and its social acceptability by the target group or segment; and 3) the compliance of the product's features with standards and regulations.

1- The consumers' acceptability of the product's organoleptic quality. Ultimately, food is conditioned upon the consumer acceptability of products. To be accepted, a food product must demonstrate acceptable organoleptic qualities. In both cases, this was tested in two ways. The first test was generally carried out on a sample of consumers in a market acceptance study with approximately 100 subjects. The second evaluation was made by the EcoTrophelia competition tasting jury that evaluated both the taste and the choice of raw materials, food-processing techniques and processes that might have an impact on the taste and nutritional value of the ingredients.

2- The marketing promise and its social acceptability by the target group. The two projects had different target groups, promises and successes. The development and growth of the start-up 'Ici&Là' demonstrated its products' organoleptic and social acceptability. The 'VitaPlus' project was considered by the technical jury as a technically successful product but a socially unacceptable project. This judgement was based on the idea that target consumers – the seniors – would feel a social divide when confronted with an offering that they would consider stigmatising. This relative failure illustrates the importance of social acceptability in food eco-innovation projects.

3- The compliance of the product's features with standards and regulations. EcoTrophelia competition called for eco-design food products. During the competition, the evaluation and selection panels included experts that could validate the legal and regulatory compliance of the products. To enter this competition, the food products had to comply with all legal and regulatory requirements. This compliance procedure was part of the specifications developed within the framework of each eco-designed project. Hygiene and sanitary quality methods, standards (such as Hazard Analysis Critical Control Point standard) had to be met. Depending on the students' resources, competences and the partnerships they developed, some projects were developed within the frameworks of management system standards such as ISO 9001 for quality management, ISO 14001 for environmental management and ISO 50001 for energy performance management. Within a life-cycle perspective, these three standards ensure compliance with three key requirements: 1) food and environmental regulations to respect; 2) the identification of the involved or impacted stakeholders to satisfy; 3) the environmental impacts of the activity to improve. The challenges of bringing eco-designed products into compliance with regulations, generic standards and voluntary application or the requirements of a client are economic, social and environmental. This compliance confirmed the eco-designed profile of the product, made it possible to improve the performance of strategic processes, reduce losses and waste, improve the image of products, and facilitate access to markets. In addition, beyond compliance with the specific regulations and satisfying consumer needs and desires, the business model framework that was used to design and analyse the projects, represents, not only a relevant generic tool to align a business strategy and business model elements with the SDGs, but it is also an artefact that helps in the creation of coupled innovations at a food system level, i.e. innovations linking agriculture, food processing and distribution to marketing and consumption.

The analysis of the projects with the business model innovation lens shows that the EcoTrophelia programme enabled the construction of a sustainable path through green niches (Kemp, Rip, and Schot 2001). Moreover, each team acquired and put into practice three skills:

First, they learned how to establish a startup and develop products that could achieve SDGs. As responsible entrepreneurs, they identified the SDG(s) they aimed to address, the technical and financial resources available, and the socioeconomic and environmental impact of each of their decisions.

Second, they acquired the management capabilities to continuously improve their projects. They learned how to identify a target customer segment, propose a relevant value, identify distribution methods, locate key

resources, ensure adequate revenue streams, undertake key activities, organise relevant partnerships, and evaluate the project cost.

Third, they learned not only the standard knowledge taught in classes but also how to apply this knowledge to solve real-world problems. The students studied the identification, modelling, and resolution of a problem with scientific and technical knowledge specific to a particular context and learned to apply their agricultural and food knowledge to real needs.

In this way, the Idefi-EcoTrophelia programme provided practical training and skills that will facilitate the transition of the students to corporate and professional environments where their ability to identify new problems and create sustainable solutions will be highly valued.

7. Conclusion

Given the environmental and social issues facing society, it is vital to understand how sustainable policies and development goals can be translated into educational programmes, tools, BMs, and, ultimately, products and services. In this research, we explored the challenges that this food eco-innovation program faced and its results. The case studies demonstrated that the development of sustainable food BMs and products with eco-design and eco-innovation practices is possible, but it requires a systematic and multidisciplinary approach.

This research has pedagogical, engineering, entrepreneurial, and managerial implications for studies on engineering sustainability.

Pedagogical implication: This research contributes to both theory development on eco-innovation and sustainability transitions through introducing the concepts of BMI and dynamic capabilities. The development of skills for teaching about environmental transition is necessary.

This research shows the importance of introducing new learning methods in higher education teaching programmes that are focused on eco-innovation. The utility of such initiatives for students, engineers, and professors was manifested at two stages of the projects' development.

Eco-design projects. The teaching of how to eco-design a business model and elaborate a food product helped the engineers develop new understanding of the links between the economy, innovation, social factors, climate change, and nutrition and how to give new meaning to their mission in the environmental transition process.

Creativity sessions, design thinking, and business model design. By discovering that eco-designing a business model or reconfiguring an existing one depends as much on art and intuition as on science and analysis, the student engineers developed the ability to methodically address the multiple and complex aspects of food sustainability by using triple-bottom-line BMs.

Engineering, entrepreneurial, and managerial implications: Sustainable engineering is the art of using various management tools and methods to design, practice, and continuously improve a product to achieve sustainability. This contribution can only be effective and fruitful if the different activities carried out in eco-innovation projects are constantly interrelated and if the local decisions are taken by participants through a systemic view of the project's performance. For these conditions to be realised, it is essential for students to be trained and able to work in an interdisciplinary manner. This paper is meant to increase the understanding of engineers and teachers about how to practice and teach engineers and young managers about sustainable development practices and policies. This contribution can also encourage established firms and recently graduated food engineers to use their skills and knowledge to help address the growing economic, environmental, and social challenges in agricultural and food systems.

The limits of this paper are twofold: First, it summarises four projects and describes only two case studies selected among hundreds of projects.

The second limitation of this study is embedded in the design and funding of the programme. Institutional learning dissipated after 2017, when the French government announced new priorities and discontinued funding, despite the programme successes. The difficulty with such short-termism is that a transition to a new

environmental paradigm will require long-term commitments that can create enduring infrastructure and cumulative learning effectively, as Garud and Karnøe (2001) suggest, creating new paths. Innovative programmes to teach hands-on eco-innovation will require sustained commitments; otherwise, path-dependent competence-enhancing innovations and food system transition pathways will not emerge.

One remarkable outcome of the most successful of these projects was their ability to bridge the gap between engineering studies and the creation of economic value. The training that these student engineers received may result in the transfer of the lessons they learned to the corporate world and have an even greater impact, as they transfer this eco-innovation learning to their new employers.

Future research

The transition research field argues that ecological transition come about through dynamic processes within and between three levels of analysis: 1) the 'green niches' where radical innovations emerge; 2) the socio-technical regime that represents the institutional structuring of the dominant agro-industrial food system; and 3) the exogenous trends and global pressures of food sustainable development.

Further research could focus on the power of the sustainable alternatives proposed by green niches such as PannIno, Ici&Là and VitaPlus, Mixi'Mousse, to hybridise and sustainably reengineer established business models and industries on the one hand; and to adjust and align food policies and regulations to their learning, visions and values on the other hand.

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Notes

1. A food mile is the distance between where a food product is grown or transformed and where it is consumed.
2. AgroParisTech, AgroSup Dijon, UL-ENSAIA, ENSCBP Bordeaux INP, ISARA Lyon, Montpellier SupAgro, ONIRIS Nantes, EBI, ESIROI Université de la Réunion, ESIX, FMA-UHA, AgroCampus Ouest, and PURPAN.
3. Here and below the quotations in italics are translated from the final reports of the engineering students who worked on the project.
4. ESEPAC is an engineering school that specialises in packaging.
5. 2PourEmballer is a company that specialises in education, counselling, and developing packaging solutions.
6. PNNS: Programme National Nutrition Santé.
7. The nutraceutical claims cited in this paper were evaluated by the professors who guided the projects analysed here. We cited the references as reported in the students-engineers' documents.

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