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A risk-oriented framework for Smart PSS design, considering value network and economic model configuration

Méthode de conception intégrée de Systèmes Produits-Services avec configuration des chaînes de création de valeur et de leurs modèles économiques

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Chapter 1. Introduction

1.1 Overview of the research context

Multiple manufacturers transform their product-centric portfolio into service-based offerings called Product-Service Systems (PSS) to maintain their competitive advantage. This changeover from selling products or services alone to selling offerings consisting of a bundle of products and services is known as servitization (Roy et al., 2009). Recently, numerous manufacturers have adopted Digital Technologies such as the Internet of Things (IoT) and Big Data and Analytics to deliver these service-based offerings (Paschou et al., 2020). These digital-enabled PSS offerings are known as Smart PSS and were defined for the first time by Valencia Cardona et al. (2014) as "*Smart products and their generated e-services integrated into a single solution that make use of disruptive Information and Communications Technology (ICT*)." The transformational process of developing Smart PSS offerings and consequently enabling new business models is known as digital servitization (Paschou et al., 2020).

Manufacturers making the transition toward Smart PSS offerings must employ systematic design approaches to ensure the successful provision of these offerings (Zheng et al., 2019). Given the plethora of PSS design frameworks, scholars have examined the direct transferability of these frameworks to the design of Smart PSS offerings (Abramovici et al., 2016; Hagen et al., 2018). These scholars have proposed extending and adjusting the current PSS design methodologies considering the particularities of the Smart PSS paradigm. These particularities notably include: (i) the fact that it is an IT-driven value co-creation process; (ii) the closed-loop design approach, (iii) and the employment of ICT that makes it a context-awareness process (Cong et al., 2020a). Hence, the formulation of design approaches for Smart PSS is a novel research subject (Pirola et al., 2020).

Scholars have documented the potential benefits that manufacturers can obtain by adopting a digital servitization strategy (e.g., recurrent revenue streams, lower environmental impacts, new platform-based business models) (Paschou et al., 2020). However, these manufacturers undertaking the digital servitization path also face several challenges (Parida et al., 2019; Linde et al., 2020). For instance, in the early design phase, industrial firms deal with the uncertainty of profitability stemming from the Smart PSS offering commercialization. In this perspective, the scenario in which the industrial firm does not meet the profitability expectations derived from the Smart PSS provision is known in the literature as the 'digitalization paradox' (Kohtamäki et al., 2020). The research work developed in this thesis addressed the challenge concerning the anticipation and mitigation during the early design phase of the various risk sources that can lead the manufacturing firm to experience the digitalization paradox. As a result, a risk-oriented Smart PSS design framework enabled by two prototyping IT tools is presented in this thesis.

This chapter describes the context of this research study and the research methodology employed in this thesis. The following sections detail the scientific positioning of the thesis and the industrial context in which this thesis was carried out. Then, the research questions that guided this thesis work are described. Lastly, the structure of this manuscript is delineated.

1.1.1 Scientific positioning

Established manufacturers tend to have a product-centric design mindset that is challenged when transitioning to the design of service-based solutions (Benedittini et al., 2015). Thus, this transformational process requires novel and well-framed design approaches whose importance in both the PSS and Smart PSS fields has been documented in comprehensive literature reviews (Cavalieri and Pezzotta, 2012; Zheng et al., 2019; Cong et al., 2020). Consequently, several design frameworks aimed at developing offerings integrating products, physical services, and, more recently, digital services are available in the literature. The scope of these design frameworks greatly varies depending on the perspective addressed by the authors (e.g., the technical details about the Smart PSS provision and the value co-creation process) (Qu et al., 2016; Pirola et al., 2020).

In this organisational transformation context, it is worth highlighting that from the perspective of a product-based firm, the development of service-based offerings represents an innovation of their traditional business model based on transactional sales. This innovation process has significant implications for the activities concerning the targeting of the customer segment, the value proposition design, the value delivery network, and the definition of the profit mechanism (Gassmann et al., 2014).

These implications associated with the provision of service-based offerings on the value creation, value delivery, and value capture processes of manufacturing firms have been described by Garcia Martin et al. (2019) and Parida et al. (2019). Notwithstanding the above, a leading gap considering the business value point of view concerns the lack of Smart PSS frameworks that incorporate the holistic design of the

elements that constitute the value processes previously mentioned (Murillo Coba et al., 2020; Alix and Zacharewicz, 2021).

In this perspective, the complexity associated with the design of Smart PSS offerings can be reduced by applying design frameworks integrating a set of guidelines, methods, and tools. The ultimate goal of these approaches should be to ensure the commercial success of the Smart PSS offering. Practitioners can measure this commercial success in profitability terms for the actors involved in Smart PSS delivery and also based on customer satisfaction indicators. As the design of a service-based offering represents an innovative business idea for a product-centric manufacturing firm, we adopt the definition of innovation risk by Osterwalder et al. (2020, p.11). These authors define these types of risk as "*the risk that a (convincing) business idea is going to fail*." This definition fits the scenario involving the failure to meet the profitability goals from the Smart PSS commercialization, described by the digitalization paradox phenomenon (Kohtamäki et al., 2020; Gebauer et al., 2020).

According to Osterwalder et al. (2020), this unprofitable scenario may emerge due to the lack of evidence collected during the early design phase about the customer desirability, and the feasibility, viability, and adaptability of the Smart PSS offering. However, these abovementioned aspects have not been addressed holistically in the Smart PSS design literature despite their vital link to the financial success of the Smart PSS offering (Linde et al., 2020).

In sum, Smart PSS literature lacks design frameworks that concurrently address the elements related to the value proposition design, value delivery configuration, and estimation of the captured value. Additionally, the management of innovation risks should be integrated into the Smart PSS design framework, considering the effects of these risk sources on the financial health of the manufacturing firm (Parida et al., 2019, Linde et al., 2020). Moreover, a Smart PSS design framework must be readily applicable in real-world manufacturing contexts instead of remaining as a theoretical proposal. Literature offers limited examples of Smart PSS design frameworks deployed in practical applications. For this reason, supporting tools that enable the operationalization of the design framework must be developed and included in the proposals. The research work presented in this thesis is aimed at filling these gaps.

1.1.2 Industrial context

Manufacturing firms increasingly rely on the provision of Smart PSS offerings to gain competitive advantages in markets characterized by fierce competition and the commoditization of products (Chen et al., 2021). Accordingly, Smart PSS design frameworks must be readily transferable to industrial settings. With this aim in mind, the research work presented in this thesis was conducted through collaborative research (Ellström, 2007) with the company elm.leblanc. This research work was part of a CIFRE (Industrial Agreements for Training through Research) PhD project. The company that partnered in this

research, elm.leblanc (Bosch Group France, www.elmleblanc.fr), is a manufacturer of gas boilers and water heaters with 90 years of presence in the French market.

The core activities of elm.leblanc are framed within the residential heating appliance business. This industrial sector is being reshaped by market disruptions and the decarbonisation of heat agenda. These factors favour the appearance of new service-based offerings enabled by Digital Technologies and new ecosystem-centric business models (Delta EE, 2019a). Given this industrial context, elm.leblanc launched this research project in partnership with the research laboratory LIMOS to develop appropriate methods and tools to assist professionals in designing these service-based and digital-enabled offerings.

Considering the growth of 'smart home' applications and the need to decarbonise the installed base of heating appliances, Smart PSS offerings represent a promising opportunity for heating appliance manufacturers, to diversify their revenue sources.

In this context, manufacturing firms encounter various challenges during the early design phase of Smart PSS offerings. First, heating appliance manufacturers must verify that their Smart PSS offerings truly address customers' and other stakeholders' needs. Second, particular attention must be paid to the configuration of new business ecosystems, where new entrants are expected to appear. These ecosystems are likely to co-exist with the product-centric value networks. Third, Smart PSS offerings' commercialization must be financially viable for the actors participating in these new business ecosystems. These challenges were addressed throughout the course of this thesis.

1.2 Research questions and objectives

Manufacturers aiming at innovating on their product portfolio, as in the case of elm.leblanc, require systematic design approaches that guide professionals about the steps to follow for designing service-oriented solutions. These solutions consist of a bundle of products and physical and digital services. To this end, the main objective of this thesis is to develop a design framework dedicated to Smart PSS offerings. In order to build this framework, the focus on risk anticipation and mitigation is emphasized, considering that traditional product-based companies are exposed to the effects of innovation risks due to the uncertainties associated with the novelty of Smart offerings in their product portfolio and, therefore, in their design practices (Benedettini et al., 2015). Conjointly, to establish the framework, the added value of different types of prototypes able to support the Smart PSS design process were incorporated. This choice was made owing to the pivotal role of the prototyping activity in reducing the complexity inherent to the design process (Osterwalder et al., 2010; Ilg et al., 2018; Lewrick et al., 2018).

This design framework is addressed from the business value perspective as the detailed technical development of products, service processes, and digital services is not in the scope of this thesis. We adopt a value-driven perspective whose focus is on the value co-creation process based on the categorization proposed by Zhen et al. (2019). One can find examples of these Smart PSS design frameworks in Liu et al.

(2018), Lee et al. (2019), and Chang et al. (2019). Consequently, the general problem statement is established as:

> **How to define and formalise a framework aimed at helping the stakeholders of Smart PSS design projects to anticipate and mitigate major innovation risks while respecting the Business Model Innovation and Value-Driven design perspectives?**

This thesis investigates how to manage, in the early design phase of Smart PSS offerings, the major innovation risks (i.e., adaptability, desirability, feasibility, and viability risks) (Osterwalder et al., 2020). These types of risks are likely to emerge as changes in the value architecture elements (i.e., the value proposition, the value delivery network, and the value capture mechanism) occur when going from the sale of pure products or services to the provision of digital-enabled and service-oriented solutions (Chen et al., 2021). The value proposition changes in this transition, going from a pure product or service to a packaged solution.

Two main aspects must be addressed to avoid the risk of investing in the design of a solution that does not attract enough customers to make the Smart PSS offering beneficial. First, designers must elicit needs that create value for customers and other key stakeholders. Second, the new service-based value proposition idea must be made tangible through visualisation tools. These tools facilitate the common understanding of the design goals within the Smart PSS design team. The value network is likely to be reshaped as new actors need to be integrated to deliver the Smart PSS offering (e.g., actors that enable products' connectivity and data analytics).

In this regard, decision-makers must mitigate the risk of not being able to deliver the Smart PSS value proposition. Thus, the value network design guidelines (Kage et al., 2016) must be applied. Moreover, the potential Smart PSS value networks must be visualised by the professionals involved in the Smart PSS design process. In order to tackle these issues, the following research questions are formulated to orientate the first part of the research process:

> **RQ1: How to develop a prototyping approach and its supporting implementation tool, which would bring a consistent solution to meet designers' needs concerning the visualization of the design object and innovation risk anticipation during the early Smart PSS design phase?**

This research question can be broken down into:

- How to elicit stakeholders' needs in a structured manner?
- How to facilitate the identification of adaptability, desirability, and feasibility risks during the early design phase?
- How to support the value proposition design and value network configuration processes using easy-to-implement prototypes?

The second part of this research process addresses the changes that occur in the value capture mechanisms. Traditionally, manufacturers capture monetary value through one-time sales. In contrast, Smart PSS offerings can be sold through new economic models like pay-per-use and outcome-based contracts. These new economic models challenge how the expected profits are estimated. Furthermore, the monetary captured value stemmed from the sale of Smart PSS offerings is shared among the actors participating in the Smart PSS value network. Therefore, the profitability analysis of the Smart PSS offering must be carried out from a multi-actor perspective. Consequently, an additional research question was formulated to orientate the second part of this research work:

> **RQ2: How to develop an economic performance simulator to evaluate the viability of alternative Smart PSS delivery networks and assist the decision-making process in the design phase?**

The abovementioned research question can be broken down into the following questions:

- From a multi-actor perspective, how to evaluate the economic performance of Smart PSS offerings in the early design phase?
- How to visualize the economic added value derived from the commercialization of Smart PSS offerings compared to traditional PSS offerings?
- How to integrate the uncertainty assessment of the economic model's input parameters into the financial performance evaluation?
- How to assist the decision-making process concerning selecting the most economically viable Smart PSS value networks?

1.3 Research methodology design

In order to meet the research objectives and answer the research questions introduced in the previous section, the following research design was formulated (Figure 1). The Smart PSS design framework built during this thesis resulted from a collaborative research approach (Ellström, 2007) in the form of a co-operation between the practitioners of the heating appliance manufacturer elm.leblanc and researchers from the laboratory LIMOS. The gaps identified in the Smart PSS literature and the industrial needs collected

from the interaction with elm.leblanc were used as the ground to develop the proposed Smart PSS design framework presented in Chapter 5.

The research methodology employed in this thesis is perceived as a case study-based research protocol (Eisenhardt, 1989). An industrial case study involving elm.leblanc was conducted to validate and illustrate the application of the proposed Smart PSS design framework. This case study concerned an all-inclusive solution that includes the availability of a connected heating appliance and the provision of a remote diagnostic service. The case study presented in Chapter 7 was developed from scratch in collaboration with elm.leblanc's professionals to test the effectiveness of the proposed framework in the early design phase.
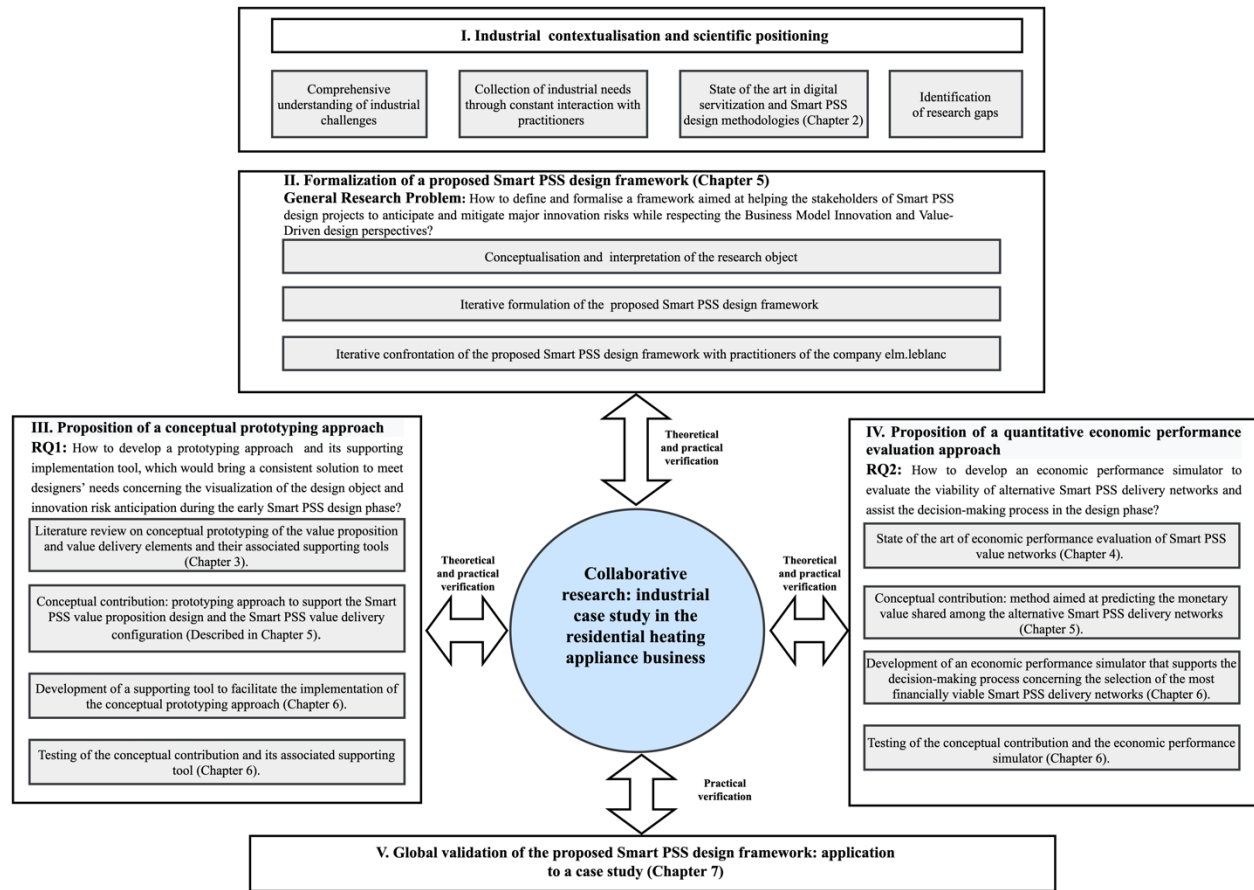
Figure 1. Research design.

The main phases of the research design adopted in this thesis are summarized with the five following steps:

Step I: The research work developed in this thesis started with the analysis of the industrial context of elm.leblanc, in which connected heating systems and service-based value propositions are progressively rising in this industrial sector. Then, the challenges that practitioners face in designing all-inclusive solutions were collected. These issues are synthesised as the need to create compelling value propositions, the concerns about the service-based offering's financial viability, and the anticipation of the major risks

that can threaten the commercial success of these types of offerings. Next, a literature review on Smart PSS design was carried out. The confrontation of the literature review findings with the industrial needs collected led to the definition of research gaps. These identified research gaps were iteratively analysed and refined in collaboration with elm.leblanc's practitioners and academic experts.

Step II: Once the research gaps and objectives were refined, a common conceptualisation and interpretation of the research problem were established and validated, as synthesized in Figure 2. In order to address the general research question, a Smart PSS design framework was built. The construction of this framework was inspired by elements of several fields such as PSS engineering, Systems Engineering, Design Thinking, and Agile development methodologies. The final proposed design framework resulted from an iterative approach, in which the structure of this framework was refined considering the industrial needs and the identified research gaps. The proposed design framework was presented to the practitioners of elm.leblanc during multiple workshops that took place between March 2019 and April 2021. These workshops were aimed to obtain feedback from the practitioners to validate the comprehension of the proposal and its usefulness. The feedback collected was used to refine the proposed design framework.

Industrial needs and research gaps	Research objectives	Research question	Outputs
Going from a product-centric to a service-based offering implies modifications of at least two of the four Business Model Innovation (BMI) dimensions (customer segment, value proposition, value network, and profit mechanism) and the emergence of innovation risks (adaptability, desirability, feasibility, and viability risks). Smart PSS literature has not fully addressed the concurrent design of the BMI dimensions and the anticipation of innovation risks.	To develop a design framework dedicated to Smart PSS offerings that enables the anticipation and mitigation of innovation risks and integrates the utilization of different types of prototypes to support the design process.	How to define and formalise a framework aimed at helping the stakeholders of Smart PSS design projects to anticipate and mitigate major innovation risks while respecting the Business Model Innovation and Value-Driven design perspectives?	Novel risk-oriented Smart PSS design methodological framework based on the value-driven perspective that integrates conceptual prototyping and quantitative simulation approaches.

Figure 2. Conceptualisation and interpretation of the research object

Step III: The conceptualisation of the research object that was transformed into a general research question led us to defining two additional research questions. These research questions were aimed to find workable solutions to operationalize the proposed Smart PSS design framework in real-world applications. The first research question was established to be related to the need to develop conceptual prototypes in the early design phase. To this end, a literature review on prototyping focused on conceptual prototyping in the PSS and Smart PSS design field was carried out. Next, we built a conceptual prototyping approach to support the value proposition design and the configuration of alternative value delivery networks.

Based on this proposed approach, we developed a supporting IT tool to enable the implementation of the proposed conceptual prototyping approach. The conceptual prototypes generated by this tool were conceived to fulfil two specific purposes. First, these conceptual prototypes serve as cognitive support for identifying innovation risks and the definition of risk mitigation strategies. Second, the IT tool serves as a knowledge repository, where the conceptual models created are linked to crucial design knowledge that is

used in the economic performance evaluation step. Both the conceptual prototyping approach and the supporting IT tool were validated by academic experts and elm.leblanc's practitioners.

Step IV: A second research question concerning the financial viability of Smart PSS offerings was formulated. In order to find a practical proposal to deal with this research question, a literature review on the economic performance evaluation of PSS and Smart PSS offerings was completed. The elements retained from the literature review served as a basis for developing a method to simulate the monetary value shared among the actors of the alternative value delivery scenarios. We built a computer-based tool to operationalise this economic performance evaluation method. Practitioners and academic experts validated the economic evaluation method and the IT tool.

Step V: The entire proposed design framework and the supporting tools built to facilitate its operationalisation were applied in an in-depth case study. The feedback collected from this case study validated the effectiveness of the Smart PSS design framework and its associated computer-based tools in an industrial setting. This case study was compatible with the gaps and research questions.

1.4 Structure of the manuscript

This manuscript comprises eight chapters which are organised in four parts. The first part covers the general introduction of this research work. The second part is structured into three chapters which describes the theoretical background of the proposal. The third part comprises three chapters exposing the proposal resulting from this thesis. This proposal consists of a novel Smart PSS design framework and the supporting tools to deploy this proposal. The proposal is validated through the application of a case study. Lastly, the final part reports this research work's conclusions, limitations, and perspectives. The thesis outline is depicted in Figure 3.

1.4.1 Part II: Theoretical background

Chapter 2: Smart PSS and Digital Servitization background. This chapter describes the ongoing trend concerning the shift from traditional PSS to Smart PSS and presents a literature review of Smart PSS design methodologies. Based on this review, key directions for risk-oriented Smart PSS design are formulated. Finally, the potential of Smart PSS offerings in the residential heating appliance industry and concretely in the activities of elm.leblanc is explicated.

Chapter 3: Conceptual prototyping approaches in value-driven Smart PSS design. This chapter aims to conduct a literature review on the visualization methods employed in Smart PSS design. To this end, the prototyping approaches utilized in PSS and Smart PSS design are summarized. Then, considering the low Technology Readiness Level (TRL) characteristic of the early design phase, this review focuses on PSS and Smart PSS modelling approaches. This chapter ends with a review of the PSS modelling techniques from the product-service perspective proposed by Phumbua and Tjahjono (2012). This category of PSS

modelling technique is further detailed because it is considered to meet the prototyping needs of the elements associated with the Smart PSS value proposition (VP) and the alternative value networks that can deliver this VP.

Chapter 4: Economic quantitative evaluation of Smart PSS offerings. This chapter explores the approaches utilized in PSS and Smart PSS literature to evaluate the economic performance of these offerings. This chapter starts with a review of the definition of the profit mechanism in PSS and Smart PSS offerings. For this purpose, the costing and definition of revenue stream processes in the design of these types of offerings were reviewed. Then, given that the presence of numerous uncertainties characterizes the economic performance evaluation in the early design phase, both the quantitative uncertainty assessment and risk management approaches utilized in the PSS and Smart PSS literature are investigated. Lastly, an overview of the simulation approaches employed to evaluate the performance of PSS and Smart PSS offerings was carried out. The key elements of these reviews were considered to build the proposal presented in Chapter 5.

1.4.2 Part III: Scientific contribution

Chapter 5: Proposal of a methodological framework for risk-oriented Smart PSS design: sPS²Risk. This chapter presents the methodological proposal for the design of Smart PSS offering from a value-driven perspective. This design framework called sPS²Risk was built to address the identified research gaps and the industrial needs collected from the collaboration with elm.leblanc. The sPS²Risk framework recommends carrying out a preliminary strategic contextualization step and then applying five methodological blocks.

This proposal aims to address the concurrent design of the Smart PSS value proposition, the configuration of alternative Smart PSS value networks, and the profitability analysis of the alternative Smart PSS value networks. Each Methodological Block is referenced with a letter from A to E. They are called respectively: (A) elicitation of stakeholders' value expectations, (B) prototyping of the general value concept, (C) specification of the detailed value concept, (D) simulation and decision-making applied to the Smart PSS delivery scenarios, and (E) development and experimental prototyping of the Smart PSS solution. The tasks included in each methodological block are detailed in this chapter. The supporting tools that enable the operationalisation of the sPS²Risk framework are mentioned in the description of the tasks.

Chapter 6: A modelling and simulation toolset to support the implementation of the sPS²Risk framework. The main intention of this chapter is to present the toolset required to implement the sPS²Risk framework and to answer respectively the research questions RQ 1 and RQ2. Specifically, two supporting computer-based tools, developed to deploy the sPS²Risk framework in a real industrial setting, are described in this chapter. The scientific positioning, the development and validation processes, and the utilization of both tools in the sPS²Risk framework are detailed in this chapter.

The first tool, called sPS²Modeller, is a modelling toolkit that creates conceptual prototypes. The sPS²Modeller also serves as a knowledge repository to store the information needed to predict the profitability of the alternative Smart PSS value networks. This modelling toolkit is employed to operationalise the strategic contextualisation step and the methodological blocks B and C. The second tool, called sPS²Simulator, is a quantitative economic performance simulation tool that estimates the expected profitability of various alternative Smart PSS value networks. This tool is employed to implement the methodological block D of the sPS²Risk framework.

Chapter 7: Application of the sPS²Risk framework to design Smart PSS offerings in the heating business. The practical implementation of the sPS²Risk framework is illustrated in this chapter with a real case study. Elm.leblanc is the focal company of this case study that concerns the design of offerings known in the residential heating industry as 'Heat-as-a-Service.' The results of the proposal's implementation allowed the recommendation of mitigation strategies for the innovation risks identified during the application of the sPS²Risk framework.

1.4.3 Part IV: General conclusion

Chapter 8: Conclusions and perspectives. This chapter summarizes the main contributions of this thesis regarding the scientific literature on Smart PSS design. Then, the limitations of this study are explained. Finally, the potential extension of this research work is described as perspectives.

1	**Introduction to the thesis**			
	Overview of the research context	Research questions and objectives	Research methodology design	Structure of the manuscript

2	**Theoretical background on Smart PSS design**			
	The shift from PSS to Smart PSS	Smart PSS design	Key directions for risk-oriented Smart PSS design	Smart PSS in the residential heating appliance industry

3	**Theoretical background on conceptual prototyping in Smart PSS design**			
	Prototyping in PSS and Smart PSS design	PSS and Smart PSS modelling background	PSS modelling techniques from the product-service perspective	The contributions of conceptual modelling in PSS and Smart PSS prototyping

4	**Theoretical background on economic evaluation of value delivery networks in Smart PSS design**		
	Profit mechanism definition in Smart PSS design	Risk and uncertainty management in PSS and Smart PSS design	Simulation approaches applied to PSS and Smart PSS evaluation

5	**Methodological proposal for the design of Smart PSS offerings**					
	Overview of the sPS^{2}Risk framework	Strategic contextualisation	Methodological Block (MB) A- Elicitation of key stakeholders' value expectations	MB B- Prototyping of the general value concept	MB C- Specification of the detailed value concept	MB D- Simulation and decision-making applied to the Smart PSS delivery scenarios

(continued) MB E- Development and experimental prototyping of the Smart PSS solution

6	**Supporting toolset to implement the methodological proposal**	
	Conceptual modelling tool	Economic performance simulation tool

7	**Case study**		
	Overview of the case study	Application of the iterative design loop	Application of the iterative validation loop

8	**Conclusions**		
	Scientific implication	Practical implications	Limits of the study and research perspectives

Figure 3. Thesis outline

Chapter 2. Smart PSS and Digital Servitization background

Introduction

"Selling a product is no longer enough. Industrial manufacturers need to design, sell, deliver, and maintain personalized solution bundles that deliver ongoing value and outcomes" (Forbes, 2021). These solution bundles are known in the scientific literature as Product-Service Systems (PSS). Companies started launching PSS offerings in the nineties. Thanks to the advances in Information and Communications Technology (ICT), new offerings known as Smart PSS appeared during the 2010s (Martín-Peña et al., 2018). Those offerings are distinguished from the traditional PSS concept for being based on digital platforms. In Smart PSS, data collected from sensors embedded in products are fundamental to creating value in a business ecosystem. These conditions recall the refrain "Data is the new oil."

A new business paradigm implies challenges to how established companies design and deliver their offerings, which is the case for manufacturing companies aiming to put Smart PSS solutions on the market. This chapter introduces the general theoretical background of Smart PSS and digital servitization and their current application in the residential heating appliance industry. Furthermore, this chapter reviews the existing Smart PSS design approaches that have been tested in different industrial fields.

The first section of this chapter briefly introduces the key differences between PSS and Smart PSS and the notion of digital servitization. Second, the main existing Smart PSS design frameworks are presented. Third, the perspective of a systematic and risk-oriented Smart PSS design approach is described based on

the literature review findings. Finally, the industrial context of the residential heating appliance sector in terms of digital servitization is presented.

2.1 The shift from PSS to Smart PSS

Traditionally, manufacturers create monetary value through one-time sales to distributors or directly to customers. However, manufacturers had to develop new strategies, different from cost and price reduction, in price-sensitive markets to gain a competitive advantage. In this context, the concept of PSS, defined as *"tangible products and intangible services designed and combined so that they jointly are capable of fulfilling specific customer needs"* (Tukker, 2004), emerged to compete by delivering value-in-use to customers. The associated organizational process consisting in going from selling products to selling solutions, including a bundle of products and services, is known as servitization (Baines et al., 2009).

Recently, the rapid development of digital technologies such as the Internet of Things (IoT) and their potential adoption by manufacturers in their value propositions derived a new business paradigm from the servitization field: the digital servitization phenomenon (Paschou et al., 2020). This phenomenon results from the convergence between servitization and digitalization in the business environment (Gebauer et al., 2021). Digital servitization is defined as "*the transformation in processes, capabilities, and offerings within industrial firms and their associate ecosystems to progressively create, deliver, and capture increased service value arising from a broad range of enabling digital technologies*" (Sjödin et al., 2020).

Companies that undertake the digital servitization path offer Smart PSS solutions. Compared to PSS solutions, Smart PSS includes digital technologies as a key differentiation factor. Therefore, integrating smart products and digital services into the offering is a distinctive feature of Smart PSS (Valencia Cardona, 2017). Additionally, we can find two other particularities of the Smart PSS concept. First, the role of data generated by smart products in the value creation process, and second, the need to establish a business ecosystem enabled by digital platforms to deliver the offerings (Pirola et al., 2020; Sklyar et al., 2019; Zheng et al., 2019; Opresnik and Taisch, 2015).

For a manufacturing firm used to a product-centric mindset, transitioning to a service-oriented or a digital service-oriented mindset poses challenges, concretely regarding business model changes (Chen et al., 2021; Martin et al., 2019). Consequently, the required modifications in the value architecture, along with the integrated design of products, services, and software, make the Smart PSS design complex (Huikkola et al., 2021). In order to address this complexity and ensure the success of the Smart PSS offering, a systematic approach must be incorporated into the design phase (Zheng et al., 2019).

2.2 Smart PSS design

The Smart PSS paradigm was first described in 2014 by Valencia Cardona (2014). Hence, due to the novelty of this subject, the literature on Smart PSS design is not as extensive as the one concerning PSS design. Abramovici et al. (2015) highlighted the importance for companies to internalize proper Smart PSS engineering methodologies to face market volatility. Those methodologies must deal with the engineering requirements specific to Smart PSS that they defined. Hagen et al. (2018) concluded from a literature review that PSS development methodologies can eventually be transferred and are also complementary to the design of Smart PSS solutions. However, they claim that new Smart PSS design methodologies are needed to address the distinct requirements of the Smart PSS paradigm more appropriately.

Cong et al. (2020a) identified three characteristics of the Smart PSS design process that makes it different from product and service development. These characteristics are IT-driven value co-creation, closed-loop design, and usage context-awareness enabled by digital technologies. Zheng et al. (2019) found that existing Smart PSS design methodologies can be classified from a value-driven approach and a product-service provision generation perspective. The former addresses the value co-creation process, and the latter focuses on the technical aspects of the value delivery process.

From a business aspect, Smart PSS design frameworks must assist the target users of the methodology with the conception and visualization of the business model changes involved in delivering a Smart PSS solution. These users are part of a cross-functional design team representing several company departments such as product development, product release management, after-sales, IT, accounting, etc. Therefore, usability plays a key role in the definition of the methods and tools used in the design frameworks (Abramovici et al., 2015).

2.2.1 Engineering methodologies employed in PSS design and their applicability in Smart PSS design

The literature on PSS design proposes different engineering methodologies to develop PSS offerings (Cavalieri and Pezzota, 2012). Some of these methodologies are grouped under Service Engineering (SE) category. This category comprises systematic approaches considering a PSS offering as a complex system, including tangible and intangible components in different lifecycle phases. Applications of Service Engineering in PSS design were notably proposed by Shimomura and Arai (2009); Kim et al. (2015); Pezzotta et al. (2015); Rondini et al. (2015), and Trevisan (2016).

Following the concept of the PSS solution as a complex system, scholars have adapted and applied the Systems Engineering theory to PSS design (Trevisan and Brissaud, 2017). Cavalieri and Pezzota (2012) found that most of those systems engineering-based PSS design methodologies followed a waterfall development model. Other scholars utilized tailored versions of the V-model to develop PSS offerings (Müller and Stark., 2010; Maleki et al., 2017). Pezzotta et al. (2012) concluded that the most suitable

development process for PSS design is the Spiral model. The main characteristic of this model is its risk-driven approach. This conclusion was the result of analysing two companies that succeeded with their PSS offerings.

Other design methods applied in the PSS field are Quality Function Deployment, TRIZ (theory of inventive problem solving), Service Blueprinting, and Functional Analysis (Cavalieri and Pezzota, 2012, Andriankaja et al., 2018). In light of the potential transferability of PSS design frameworks (Hagen et al., 2018), PSS design methodologies based on a system approach seem to be a solid groundwork for Smart PSS design. Yet, adjustments are needed to include the particularities of the Smart PSS paradigm (Murillo Coba et al., 2020a). This point is further developed in Chapters 3 and 4.

2.2.2 Contribution of current Smart PSS engineering frameworks

Table 1 displays the existing Smart PSS, data-driven PSS, and smart service design frameworks in the literature. Smart service was included since it fits the concept of Smart PSS (Anke, 2019). Most frameworks related to Smart PSS development cover the design stage, including the requirement management phase and the development of products and services. Frameworks including other engineering lifecycle stages such as manufacturing, distribution, usage, and end-of-life are scarce.

A minor part of the frameworks found in the literature aims to address aspects such as sensor technology and connectivity, data storage, and data analytics. Additionally, we can notice that most current frameworks focus on the value co-creation process and business model reconfiguration. Zheng et al. (2019) label the former design frameworks as a 'value-driven co-creation process' and the latter as ' a data-driven platform-based solution design process.' The value-driven approach, originating from the System Engineering theory, was proposed as the foundation for methodological guidance and decision support in PSS design by Bertoni and Bertoni (2016).

Existing value-driven frameworks in Smart PSS design mostly take the perspective of the service provider and the customer. The perspective of other key players of the Smart PSS ecosystem, such as manufacturers, maintenance and insurance companies, and dealers, is often not reported. Therefore, evidence of the win-win relationships of the Smart PSS ecosystem's actors is not always depicted. Furthermore, methods and tools to support the design phase are not regularly described. These value-driven co-creation frameworks tend to focus on customer requirements, and value proposition design (Liu et al., 2020; Sala et al., 2020; Chang et al., 2019; Jussen et al., 2019; Lee et al., 2019), value delivery configuration is less addressed (Kaiser et al., 2021; Liu et al., 2018), while value capture is the least addressed dimension in current Smart PSS design literature. These elements are further elaborated in Chapters 3 and 4.

A notable direction in Smart PSS design is the introduction of agile solution development (Sjödin et al., 2020; Huikkola and Kohtamäki, 2020; Wiesner et al., 2019; Jussen et al., 2019; Beverungen et al., 2018).

The application of these agile methods aims to deal with the ever-changing customer needs, an important characteristic of the Smart PSS concept (Valencia Cardona, 2014), the communication with stakeholders, and shorter time-to-market requirements. In the PSS design field, the suitability of agile methods was a recent discussion subject (Blüher et al., 2019; Hernandez et al., 2019; Murillo Coba et al., 2019) that has been transferred to Smart PSS design, where the agile software development methods are employed to build digital services.

2.3 Key directions for risk-oriented Smart PSS design

For a manufacturing firm, the transition from a product-centric mindset to a solution-oriented mindset can be considered from the point of view of business model innovation (BMI) (Frank et al., 2019). In this transformational process, manufacturers face challenges arising from the integration of new stakeholders and the appearance of new cost and risk models (Abramovici et al., 2015). Thus, adjustments in the business model are expected. In the BMI context, Gassmann et al. (2014) claim that a business model is composed of four dimensions: the customer, the value proposition, the value chain, and the profit mechanism (Figure 4). These authors argue that if two or more of these dimensions are modified, then the firm's business model is being innovated. This is the case in the digital servitization process, where manufacturers often design a new value proposition, reshape the product-centric value network, and create new revenue sources (Parida et al., 2019). Due to the innovativeness of the service-based offering within the manufacturing company, new risks that were not traditionally considered in the classical product development may emerge.

Figure 4. Business Model Innovation dimensions (Gassmann et al., 2014)

Osterwalder et al. (2020) define four types of innovation risks that may emerge in this BMI environment: desirability, feasibility, viability, and adaptability risks. Desirability refers to the probability that customers are not willing to pay for the Smart PSS solution. Feasibility risk concerns the possibility that the

manufacturing firm could not have access to key resources and partners to deliver the Smart PSS solution. Viability risks involve the scenario where the manufacturing company and its key partners could not generate enough profit by delivering the Smart PSS solution. Finally, adaptability risks arise from external factors that can endanger the implementation and profitability of the Smart PSS solutions (e.g., market regulations, macroeconomic factors, disruptive technologies).

Being able to anticipate such risks in the early stages of the Smart PSS design phase is crucial to avoiding the digitalization paradox. This is a phenomenon where revenues generated by Smart PSS solutions are not sufficient to cover the costs associated with the delivery of the Smart PSS offerings (Gebauer et al., 2020; Kohtamäki et al., 2020; Sjödin et al., 2020). To cope with early risk identification, Pezzotta et al. (2012) proposed to adapt the Spiral Model to PSS engineering, considering the relevance of the iterative design process and customer involvement. The Spiral Model relies on four principles that match the challenges of Smart PSS design. These principles are stakeholder value-based guidance, incremental commitment and accountability, concurrent multidiscipline engineering, and evidence-and risk-based decisions (Boehm et al., 2014). This last principle implies the need for gathering evidence to continue with the incremental development of the solution based on progressive risk assessment.

2.3.1 Risk management in Smart PSS development

The main goal of risk management in the Smart PSS design process is to prevent decision-makers from pursuing actions based on the outcomes of the decision-making process that could badly affect the firm's financial health (Benedittini et al., 2015). Herzog et al. (2014) highlighted the importance of integrating risk management in the early design phase of PSS offerings and extending it to the management of uncertainties. Since new risk sources appear in Smart PSS development compared to PSS (e.g., data handling issues, co-alignment of the value propositions of the new Smart PSS ecosystem actors, lack of IT capabilities), risk management continues to play an important role in Smart PSS design (Birkel et al., 2019). However, the only mention of risks found in current Smart PSS development frameworks belongs to Liu and Ming (2019). These authors address the risks of failure of Smart PSS delivery by using the Failure Mode Effect and Criticality Analysis (FMECA). This approach focuses on risks associated with the operation of digital services and smart products rather than on innovation risks.

In PSS design, we find examples of uncertainty management in Erkoyuncu et al. (2019), Murillo Coba et al. (2019), Kreye et al. (2014), and Erkoyuncu et al. (2014). Ramirez Hernandez and Kreye (2021) characterized the uncertainty types that manufacturing firms face when engaging supplier co-creation to deliver PSS offerings. Regarding risk management in PSS design, scholars introduced decision-making frameworks (Dahmani et al., 2020; Reim et al., 2016) and risk assessment methods (Wang et al., 2018). Reim et al. (2016)

identified risk categories from the business model perspective that manufacturers confront when offering PSS solutions.

The role of risk and uncertainty management during the early design process has been acknowledged as pivotal for the Smart PSS offering's success (Parida et al., 2019). However, the integration of qualitative and quantitative risk and uncertainty management approaches into the Smart PSS design is lacking in the literature. As the digital servitization transformation process entails an innovation process of the manufacturing firms' offerings, special attention must be paid to innovation risks described by Osterwalder et al. (2020). Consequently, the customer desirability of the Smart PSS solution and the feasibility of building the network to deliver this solution must be anticipated during the early design phase, while the viability risk of developing and selling this solution must be quantified.

2.4 Smart PSS in the residential heating appliance industry

Manufacturers of residential heating appliances such as gas boilers and heat pumps encounter new challenges in their long-established business models. These challenges are posed by the commoditization of their products, the ongoing energy transition trend, and the growing popularity of smart home functionalities. In this context, manufacturers in this industrial sector must produce and distribute high-energy efficient appliances to meet heat decarbonisation targets (Climate exchange, 2021). However, these appliances tend to be high-priced. This situation hinders the mass adoption of these energy-saving heating technologies due to households' financing constraints.

Additionally, when it comes to installing a new heating system, customers rely on installers and heat engineers to choose the appliance brand. This circumstance reveals that customers are more interested in the heating system outcome, a warm home, and hot water supply than in the product itself. In the residential heating appliance market, there are three types of customer segments: private homeowners in the heating system retrofit market, social housing companies, and property developers (Figure 5). Each one of these customer segments has specific needs related to the acquisition and operation of heating systems.

Given this context, some heating appliance manufacturers declared to be pursuing the strategy of transitioning from product providers to solution providers (Viessman, 2021). This solution-provision mindset creates opportunities for new service-based business models. In the residential heating market, we find business models such as heat as a service, comfort as a service, and energy as a service (Delta-EE, 2021). In the social housing market, zero-energy outcome-based contracts such as the Energiesprong initiative (Energiesprong, 2021) are gaining ground, representing an opportunity for heating manufacturers. To enrich the value propositions embedded in these service-based business models, companies in this industry started developing digital services. These digital services aim to improve the service experience of installers, maintenance technicians, and end-users (e.g., online training for installers, indoor temperature controlling for end-users). The most prevalent digital service offered by heating manufacturers is the remote

monitoring of the heating appliance. This monitoring activity enabled by connectivity allows staff involved in the maintenance of the appliance to identify any malfunctions or faults. Service engineers are informed in real-time of the breakdown of the appliance or even before the occurrence of the breakdown. Service engineers are also notified about the part that needs repairing or replacement. Examples of companies offering this digital service in the private homeowner market are British Gas and Mitsubishi Electric in the United Kingdom, Engie Home Services in France, Thermondo in Germany, and Feenstra in the Netherlands. In the social housing market, elm.leblanc and Chaffoteaux offer this remote diagnostic service in France for the gas boilers they fabricate.
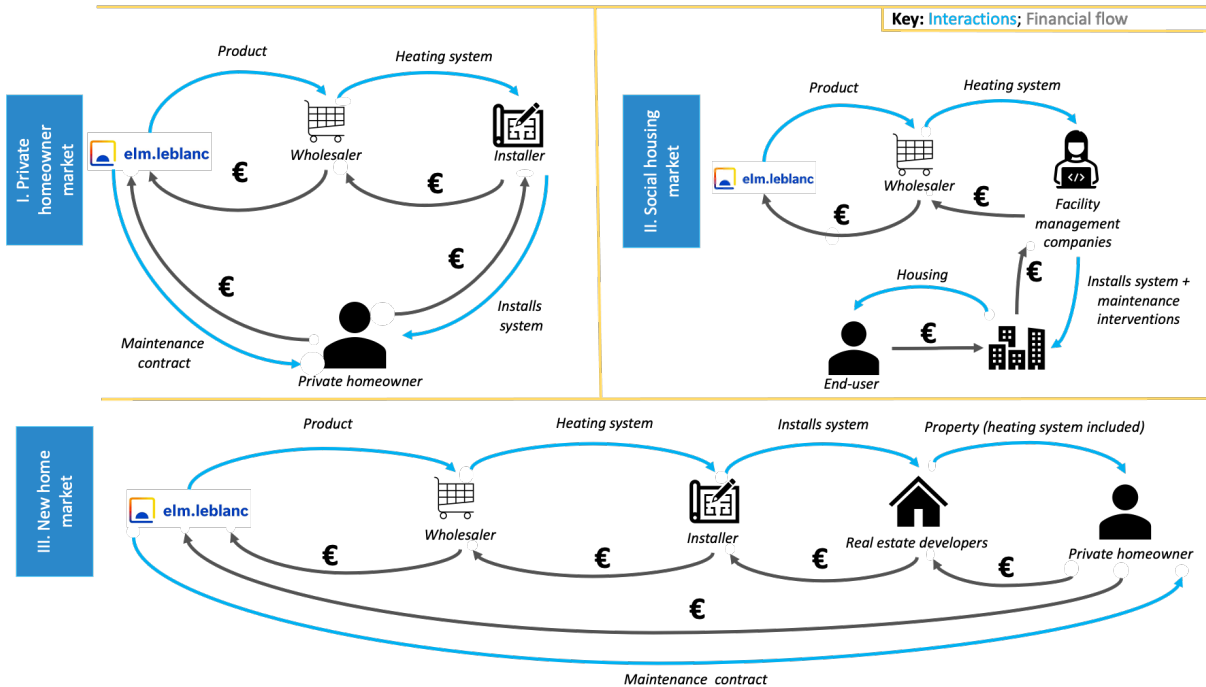
Figure 5. Customer segments in the residential heating appliance industry.

Several service providers (Engie Home Services, Thermondo, and Feenstra) added remote diagnostic services as part of their value proposition in the different variants of the Heat-as-a-Service (HaaS) business model. These HaaS variants are aimed at the private homeowners' market (See Figure 6). These current offerings support the recognition of remote monitoring technology as a key enabler of servitization (Grubic, 2018). Finally, as servitization is considered a promising approach to decarbonizing heat, heating manufacturers are expected to play a key role in the implementation of service-based models. Thus, risk-oriented systemic approaches to designing Smart PSS solutions will be key for heating manufacturers to seize the opportunities derived from these 'as-a-service' business models and create sustainable value.

Table 1. Summary of existing Smart PSS design frameworks.

Author	Year	Title	Design perspective	Engineering methodology / Design method employed	Application
(Wu et al., 2021)	2021	A function-oriented optimising approach for smart product service systems at the conceptual design stage: A perspective from the digital twin framework	P-SPG[*]	TRIZ	Intelligent cleaning robot
(Yang et al., 2021)	2021	Emotional design for smart product-service system: A case study on smart beds	Value-driven	Analytic hierarchy process	Smart beds
(Jia et al., 2021)	2021	A synthetical development approach for rehabilitation assistive smart product–service systems: A case study	P-SPG[*]	Not mentioned	Smart rehabilitation assistive device
(Kaiser et al., 2021)	2021	Conceptualising value creation in data-driven services: The case of vehicle data	Value-driven	Not mentioned	Automobile
(Kortum et al., 2021)	2021	Engineering of Data-Driven Service Systems for Smart Living: Application and Challenges	Value-driven	Systems engineering, service engineering	Smart living
(Chiu et al., 2021)	2021	Developing a personalized recommendation system in a smart product service system based on unsupervised learning model	Value-driven	Not mentioned	Taxi operators
(Bulut and Anderl, 2021)	2021	Framework approach for smart service development	P-SPG[*]	Non-guided development	Robotic vacuum cleaner.
(Huikkola and Kohtamäki, 2020)	2020	Agile new solution development in manufacturing companies	Value-driven	Systems engineering (waterfall) and agile methods	Not reported
(Watanabe et al., 2020)	2020	Evolutionary design framework for Smart PSS: Service engineering approach	P-SPG[*]	Service engineering	Restaurant business
(Liu et al., 2020)	2020	A framework with hybrid approach to analyse system requirements of smart PSS toward customer needs and co-creative value propositions	Value-driven	Not mentioned	Smart fridge
(Sjödin et al., 2020)	2020	An agile co-creation process for digital servitization: A micro-service innovation approach	Value-driven	Agile development methods	Mining, telecom equipment, construction equipment,
(Sala et al., 2020)	2020	The Data-Driven Product-Service Systems Design and Delivery (4DPSS) Methodology	Value-driven	Systems engineering	Not reported
(Cong et al., 2020b)	2020	Design entropy theory: A new design methodology for smart PSS development	P-SPG[*]	Design entropy	Smart Travel Assistant
(Pan et al., 2019)	2019	Smart product-service systems in interoperable logistics: Design and implementation prospects	Value-driven	Not mentioned	Logistics
(Liu et al., 2019)	2019	A framework integrating interval-valued hesitant fuzzy DEMATEL method to capture and evaluate co-creative value propositions for smart PSS	Value-driven	TRIZ	Smart fridge
(Liu and Ming,2019)	2019	A methodological framework with rough-entropy-ELECTRE TRI to classify failure modes for co-implementation of smart PSS	P-SPG[*]	Not mentioned	Smart fridge
(Chang et al., 2019)	2019	A user-centric smart product-service system development approach: A case study on medication management for the elderly	Value-driven	Service blueprint	Medication management for the elderly
(Exner et al., 2019)	2019	A method to design Smart Services based on information categorization of industrial use cases	Value-driven	Not mentioned	Lightning
(Jussen et al., 2019)	2019	Smart service engineering	Value-driven	Service engineering	Textile machine industry

(Poeppelbuss and Durst, 2019)	2019	Smart Service Canvas–A tool for analyzing and designing smart product-service systems	Value-driven	Not mentioned	Sawing machines
(Lee et al., 2019)	2019	A structural service innovation approach for designing smart product service systems: Case study of smart beauty service	Value-driven	PSS engineering and service engineering, TRIZ and service blueprint	Smart beauty service
(Wiesner et al., 2019)	2019	Applicability of agile methods for dynamic requirements in smart pss development	Value-driven	Agile development methods	Virtual training
(Kampker et al., 2019)	2019	Business models for industrial smart services–the example of a digital twin for a product-service-system for potato harvesting	Value-driven	Not mentioned	Agricultural machinery
(Zheng et al., 2018)	2018	A systematic design approach for service innovation of smart product-service systems	P-SPG*	Not mentioned	Smart wearable mask
(Mittag et al., 2018)	2018	Building blocks for planning and implementation of smart services based on existing products	Value-driven	Not mentioned	Elevator
(Liu et al., 2018)	2018	A perspective on value co-creation-oriented framework for smart product-service system	Value-driven	Not mentioned	Smart fridge
(Beverungen et al., 2018)	2018	Recombinant service systems engineering	Value-driven	Systems engineering, service engineering	Agriculture machines
(Cedeno et al., 2018)	2018	Developing smart services by internet of things in manufacturing business	Value-driven	Not mentioned	Agricultural tractor
(Marilungo et al., 2017)	2017	From PSS to CPS design: a real industrial use case toward Industry 4.0	Value-driven	Previous PSS engineering frameworks	Plastic pipe manufacturing company
(Scholze et al., 2016)	2016	Novel Tools for Product-service System Engineering	P-SPG*	Not mentioned	Automobile, home appliances, automated machines for shoe production

P-SPG*: Product-service provision generation
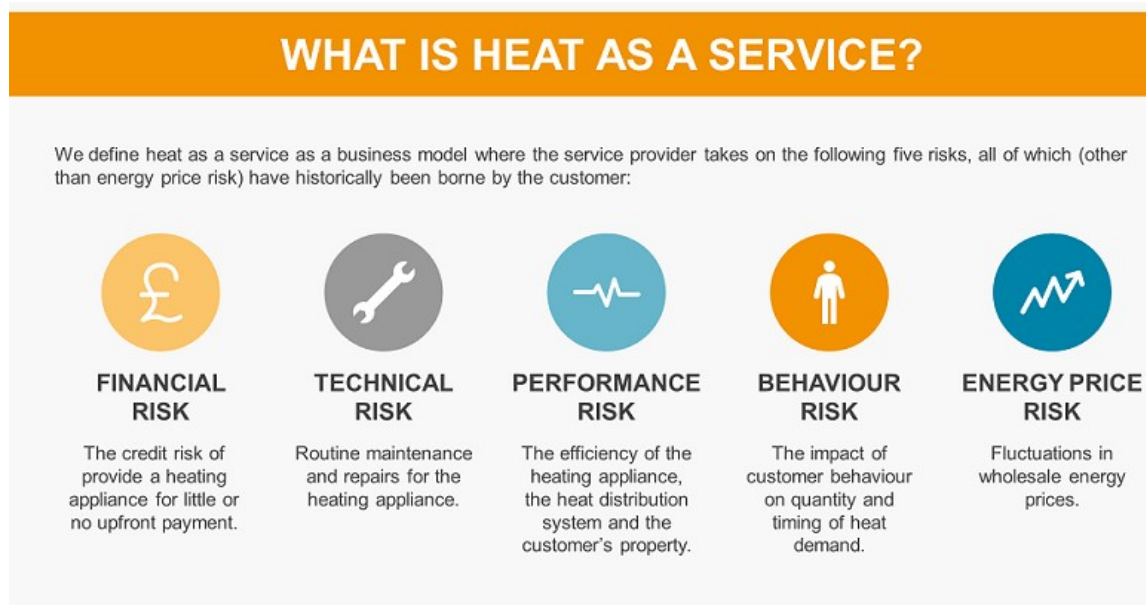
Figure 6. Definition of the 'Heat-as-a-service' business model (Delta-EE, 2019b).

2.4.1 Elm.leblanc in the context of Digital Servitization and Smart PSS provision

The French government banned oil boiler sales and gas boiler installation in new homes to reduce CO_2 emissions. These new regulations represent threats and opportunities for elm.leblanc. The company is aware of the need to embrace new service-based models, as stated by the operational marketing manager: "We *need to develop services. We all, heating manufacturers, have similar products. It is difficult to come up with revolutionary technologies. The difference will not be made on the technology or the product itself but on the service. This is where we need to work. We are working on supporting installers in the field. We already have things in place and ideas for later, tools to facilitate the work of our clients to develop their business with us."*

Elm.leblanc launched a gas boiler remote monitoring service in 2006. This service was included in one of the after-sale contracts that the firm offers. However, it was not commercially successful. The reasons that explained this unsatisfactory commercial result were the fact that end-users were wrongly considered as the customers interested in the solution, the difficulty for after-sales staff to use the remote diagnostic service, and the technical aspects of the solution that were aging and not very scalable (Hervé, 2016).

Having learned the lessons from this experience, elm.leblanc is keen to develop the methods and tools necessary for the design of these service-based solutions to keep its competitive advantage. Since elm.leblanc does not have all the technical capabilities to deliver these solutions, a special focus is made on the building of the multi-actor value networks necessary to put these solutions on the market. Profit generation for the actors involved is acknowledged as being crucial for the success of these solutions. Thus, elm.leblanc launched this Ph.D. research to create a design approach that can guide the firm on how to position itself in these value networks (i.e., the products and services offered by the firm, the

firm's role, the monetary value captured from selling these solutions, and the main risks for the firm). This design approach is aimed to be integrated into the firm's routines. The products, services, and digital services currently commercialized by elm.leblanc are the starting point for this research. Hence, the focus of the proposal resulting from this Ph.D. research does not lie in the technical development of products, services, and digital services. Instead, this thesis' focus lies on the business value perspective. Special attention is given to the definition of the service-based value propositions, the configuration of the value networks to deliver these value propositions, and the economic viability of service-based offerings under different economic models. The design proposal and its associated supporting tools are expected to assist elm.leblanc's professionals in the design of new offerings. Therefore, the resulting Smart PSS design framework and tools to implement this framework are expected to be easily transferable to the company's operating activities.

Conclusion

In order to provide the general background for this Ph.D. thesis, this chapter concisely examined the changeover from PSS and servitization to Smart PSS and digital servitization. Then, the chapter reviewed how the design of Smart PSS offerings has been addressed in the literature, where the application of agile development methods with iterative design loops is becoming more used. Besides, this chapter explored the notion of systematic risk-driven design approaches in Smart PSS design, based on the findings of Pezzotta et al. (2012). These authors concluded that an adapted Spiral development model from the systems engineering theory to PSS engineering could ensure the commercial success of a PSS offering during its conceptualisation and design phases.

The risks associated with changes in industrial firms' business models are in the spotlight of the Smart PSS design approach. The focus on these risk sources can be explained considering that technical risk management in product and software development is often part of industrial firms' practices. These business model configuration-related risks fit the definition of innovation risks by Osterwalder et al. (2020). Four aspects are encompassed in this innovation risk categorization: the customer desirability of the offering, the feasibility of building and delivering the offering, the economic viability, and the external factors that can endanger the implementation of the offering. Finally, this chapter presented the main business trends in the residential heating appliance industry concerning digital servitization and the challenges that this market environment poses for elm.leblanc.

The following two chapters present the approaches and tools used in PSS and Smart PSS design to conceptualize the value proposition, the value network, and the profit mechanism of these service-based offerings. Additionally, the next two chapters explore how these approaches and tools facilitate the collection of insights about the customer desirability of these offerings, the configuration of the required value delivery networks, and the economic viability assessment of these value network configurations.

Chapter 3. Conceptual prototyping approaches in value-driven Smart PSS design

Introduction

The increasing popularity of value offerings enabled by digital platforms such as Netflix and Spotify has inspired industrial firms to launch 'product-as-a-service' offerings. These subscription-based offerings propose all-inclusive solutions rather than a product's ownership. 'Product-as-a-service' offerings are not new in the Business-to-Business (B2B) context, where industrial PSS contracts have existed for a long time. For instance, Hilti offers the tool fleet management service as an alternative to the one-off purchase of tools. However, these offerings started appearing more recently in the Busines-to-Consumer (B2C) context.

Service-based value offerings, including consumer goods, such as the rental of household appliances, clothing, sports equipment, or furniture, have emerged. Moreover, the adoption of digital technologies such as IoT in domestic appliances, like dishwashers and ovens, paves the way for implementing Smart PSS offerings in the consumer goods field, which is the case of heating appliances. As introduced in section 2.4, several companies have included IoT-enabled services in their Heat-as-a-Service (HaaS) offerings. Hence, heating appliance manufacturers are expected to adopt a holistic approach in their design practices.

An industrial firm accustomed to designing pure products or pure service contracts, as is the case of elm.leblanc, may face challenges when designing a solution that includes products, services, and digital services. Considering that these all-inclusive solutions represent an innovation to the industrial firm's business model, design techniques used in the Business Model Innovation (BMI) process are expected

to be transferable to the Smart PSS design process. Osterwalder and Pigneur (2010) suggest employing design techniques such as customer insights, visual thinking, prototyping, storytelling, and scenarios in this BMI context.

From a business value perspective, these design techniques must be supported with quantitative and qualitative tools aimed to (i) evaluate the Smart PSS concept design, (ii) facilitate communication within the design team, and (iii) obtain a holistic understanding of the system being developed to deliver the solution (Abramovici et al., 2015). This chapter presents the design techniques, methods, and tools used in the Smart PSS and PSS design literature to conceptualise two of the BMI's dimensions (Figure 4): the value proposition and the value network. Chapter 4 describes the same aspects concerning the third remaining dimension, the profit mechanism. This choice is explained by the fact that the question about how monetary value is generated from the Smart PSS offering requires a quantitative approach addressed in Chapter 4. Furthermore, this chapter addresses the innovation risks associated with these BMI dimensions, reported in the Smart PSS and PSS literature. The question that guided the writing of the review presented in this chapter was: *what tools have been used in PSS and Smart PSS design to visualize the system being developed, specifically the elements associated with the value proposition and value network dimensions of the BMI perspective?*

This chapter is structured as follows: Section 3.1 introduces the most used design technique to support the design of PSS and Smart PSS offerings: prototyping. Then, section 3.2 presents the central notions of the PSS modelling technique, the term coined to create prototypes in PSS design. Next, section 3.3 focuses on the category of modelling techniques named "product-service perspective" by Phumbua and Tjahjono (2012), which was identified as the most appropriate category to prototype the offering's value proposition and value network elements. Based on the review of the "product-service perspective" modelling techniques, conceptual modelling is identified as a pertinent prototyping approach for Smart PSS design. Its key concepts are described in section 3.4. The added value of using conceptual modelling to support the design step of "value proposition design" while identifying risks associated with the Smart PSS value proposition is presented in section 3.4.1. Section 3.4.2 follows the same logic of the previous section for the design step of the "value delivery configuration process."
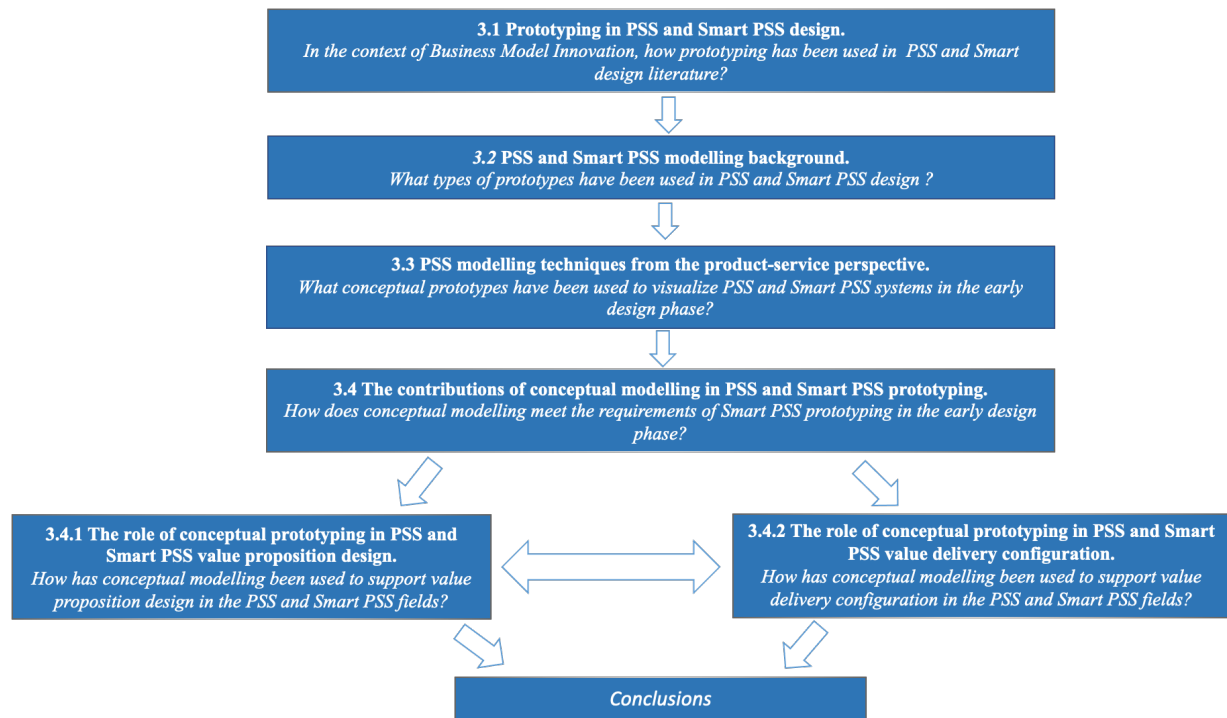
Figure 7. Outline of the Chapter 3.

3.1 Prototyping in PSS and Smart PSS design

Pezzotta et al. (2016) identified four consecutive phases in PSS design frameworks: customer analysis, requirements analysis, PSS design, and PSS test and implementation. This sequence relies on identifying target customers and collecting their needs as the first step. Then, the requirements that the PSS value proposition must fulfil are defined based on the needs previously identified. Next, the value proposition components that address the requirements detailed beforehand are established and designed, including the PSS value delivery network. Lastly, the PSS solution's performance is tested. The PSS solution is implemented based on the performance assessment results.

In this design sequence, it can be deduced that after identifying customers' needs, professionals involved in designing these offerings must outline the system associated with the designed object (the Smart PSS solution). This system needs to be visualised throughout the design process for refinement purposes. In product development, mechanical engineers use Computer-Aided Design (CAD) software programs to foresee the product's appearance without building it. The same approach is needed in Smart PSS design, where an interdisciplinary design team must conceive the Smart PSS value proposition and its associated value delivery network (Murillo Coba et al., 2020; Alix and Zacharewicz, 2021).

Among the design techniques suggested by Osterwalder and Pigneur (2010), prototyping stands out as the most addressed technique in PSS design literature (Exner et al., 2014; Tran and Park., 2015; Exner et al., 2016; Peruzzini et al., 2016; Ilg et al., 2018; Karagiannis et al., 2022). Exner et al. (2015) summed up the main characteristics of a prototype in PSS design. According to these authors and as recapitulated by Ilg et al. (2018), a PSS prototype: (i) visualizes mental ideas, (ii) supports the comprehension of

complexity, (iii) enables communication, (iv) contains a specific question, and (iv) tests functionalities and requirements.

Prototyping is also a key phase of the micro cycle of the Design Thinking problem-solving approach (Figure 8). This human-centred and systematic approach focuses on the deep comprehension of customer needs (Brown, 2008). The applicability of Design Thinking in the PSS design process was advocated by Scherer et al. (2016). These authors highlight the ability of Design Thinking's guidelines and tools to collect not only customers' articulated needs but also the unarticulated ones to translate them into PSS requirements. It is essential to observe that in Smart PSS design, customers are not the only key stakeholders; for example, actors of the product-centric value chain play a significant role in the success of a potential Smart PSS offering. These actors can act as saboteurs, influencers, recommenders, economic buyers, decision-makers, and end-users (Osterwalder et al., 2014). Therefore, managing different stakeholders' needs becomes challenging (Valencia Cardona et al., 2014).
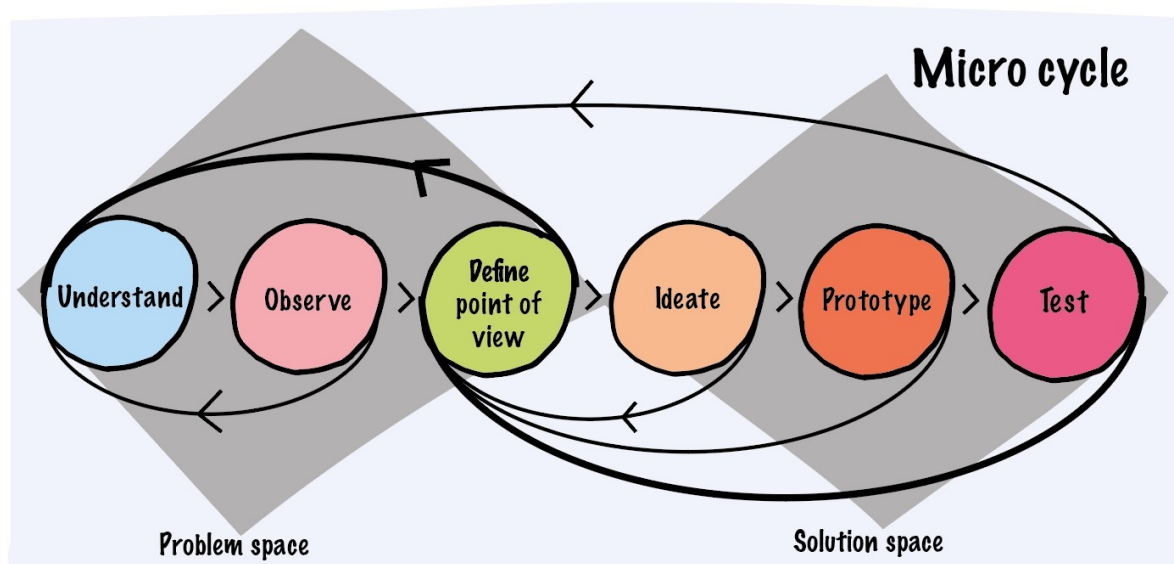
Figure 8. The Design Thinking micro cycle (Lewrick et al., 2018).

According to Ilg et al. (2018), PSS prototypes enable the global visualisation of the PSS offering, including all its components and no single components separately. Moreover, a PSS prototype is expected to facilitate customer integration and the testing and validation of the PSS offering. In the validation stage, designers evaluate whether the design object meets the purposes of the solution requirements (Exner et al., 2014). Dewit et al. (2021) stressed the importance of frequent validation between the different phases of the design process. Hence, prototyping plays a pivotal role in the PSS design process.

Lewrick et al. (2018) classified prototypes according to their level of detail into three categories: low-, medium-, and high degree of resolution. These authors suggest that prototypes categorized as low-resolution are appropriate to be applied in the early design phase (Table 2). Medium- and high-resolution prototypes are convenient, respectively, when there is a more mature solution, and the end solution is close to formalization. This prototype categorization supports the findings by Ilg et al. (2018), who

concluded that a single PSS prototype is not feasible. Instead, different types of prototypes can be utilised in each phase of the design process. These authors propose to apply tools such as actor network map, business model canvas, IDEF0 diagrams, function models, storyboards, and system maps, in the design phases corresponding to idea generation, potential analysis, requirement analysis, and PSS design. These low-resolution diagrams fit the concept of model, defined by Selic (2003) as *"a reduced representation of some system that highlights the properties of interest from a given viewpoint."* Since the context of this research is the collaboration with a manufacturing company that explores the possibility of offering service-based offerings, the remaining literature review focuses on prototyping tools used in the early design phase. The technical development of the Smart PSS solution is out of the scope of this Ph.D. thesis.

Table 2. Prototype categorization by Lewrick et al. (2018).

Degree of resolution	Point in time in the design process	Examples of prototypes
Low	Early design phase	Sketch, wireframe, chart, objects built with paper, storytelling, storyboards, video, photo, physical model, service blueprinting, business model canvas, bodystorming, Pinocchio, pretend to own, relabel, wizard of oz, minimum viable product (MVP).
Medium	Initial approaches to a solution	Mock-up, chart, storytelling, storyboards, video, open hardware platforms, service blueprinting, business model canvas, bodystorming, pretend to own, wizard of oz, MVP, minimum viable ecosystem (MVE).
High	Close-to-end solutions	Storytelling, open hardware platforms, service blueprinting, business model canvas, pretend to own, MVP, MVE.

The elaboration of models to support the early PSS design phase has widely been addressed in the literature (Phumbua and Tjahjono, 2012; Alix and Zacharewicz, 2012; Trevisan and Brissaud, 2016; Boucher et al., 2019). This activity is coined 'PSS modelling.' These models are employed in the early design phase to visualize the system that will be built to deliver the PSS solution. The following subsection further elaborates on PSS modelling. Concerning the scope of what system elements should be modelled, Trank and Park (2015) defined nine elements to represent a PSS as a system and to be modelled: product, service, process, parameters, network, stakeholders, and value proposition.

Alternatively, the most common approach to decomposing PSS into subcomponents is the employment of the Business Model concept proposed by Osterwalder and Pigneur (2010) as *"the rationale that describes how an organisation creates, delivers, and captures value*." Thus, the representation of PSS by using the nine building blocks of the Business Model Canvas (Figure 9) is prevalent in the PSS literature (Adrodegari et al., 2017). These building blocks are customer segments, value propositions, distribution channels, customer relationships, revenue streams, key resources, and key activities. Euchner and Ganguly (2014) indicated that the Business Model Canvas does not represent either the relationship among the business model elements or the competitive advantage. For instance, this canvas does not show how the key activities are interlinked with the key partners. Moreover, these authors

argue that this canvas does not provide evidence of the business model's profitability. Additionally, this canvas does not depict the key partners' win-win conditions, which are crucial to the business model's success.

Figure 9. Business Model Canvas (Osterwalder & Pigneur, 2010).

To sum up, in the early design phase, low-resolution prototypes are employed to make the transition from abstract ideas to tangible concepts that can be discussed and validated. These prototypes are aimed to: (i) create a shared understanding of the service-based offering's design goals, (ii) identify risks associated with the customer desirability and the value delivery network's feasibility, and (iii) depict the interrelationships amongst the value proposition and value network components. As agile approaches' applications become more widespread, among other reasons to shorten time-to-market, prototypes in the design phase must be quick and inexpensive to create and easily understandable. PSS literature has addressed the creation of these kinds of prototypes under the term 'PSS modelling'. The following section introduces the main concepts related to PSS and Smart PSS modelling.

3.2 PSS and Smart PSS modelling background

Phumbua and Tjahjono (2012) classified PSS modelling techniques into three categories. These categories are user focus, system focus, and product-service focus:

- Service blueprinting is the most common user-focus modelling technique in PSS design. It is a conceptual prototype covering a somewhat limited domain of PSS related to the processes involved in PSS delivery.

- Simulation techniques correspond to the system focus modelling techniques. Since these system-focused techniques deal with quantitative PSS performance assessment rather than the conceptual prototyping of the PSS solution, they will be addressed in the next chapter.

- Methods implanted in the design field such as Theory of Inventive Problem Solving (TRIZ) and Quality Function Development belong to the product-service focus category, along with diagrams such as stakeholder maps and meta-modelling. Given that we aim to prototype the elements associated with the PSS value proposition and its associated value network(s) in the early design phase, this product-service perspective modelling will be further described in the following subsection.

Table 3 presents the modelling techniques used in the most recent Smart PSS design approaches. These modelling techniques are classified according to the categorization proposed by Phumbua and Tjahjono (2012). Abramovici et al. (2015) emphasize that Smart PSS design methodologies must focus strongly on the design team staff as users of the methodology. Therefore, the design methodology's modelling outcomes must be visually intuitive and easy to use.

Table 3. Recent modelling techniques used in Smart PSS design.

Author	Title	Modelling technique category	Modelling technique	Contribution	Application
Wu et al. (2021)	A function-oriented optimising approach for smart product-service systems at the conceptual design stage: A perspective from the digital twin framework	Product-service focus	TRIZ function modelling	Proposition to develop the conceptual structure of Smart PSS based on the Digital Twin five-dimensional structure and the functional modelling method.	Cleaning robot
Kaiser et al. (2021)	Conceptualising value creation in data-driven services: The case of vehicle data	Product-service focus	Object-oriented modelling	Proposition of a multi-actor model for value creation in-vehicle data-driven services consisting of ecosystem actors and their data sharing relationships.	Automobile
Jia et al. (2021)	A synthetical development approach for rehabilitation assistive smart product-service systems: A case study	Product-service focus	Stakeholder network	Includes value network analysis in the user needs analysis.	Rehabilitation assistive devices (RADs)
Halstenberg et al., (2021)	Knowledge transfer and engineering methods for smart-circular product-service systems	Product-service and user-focus	Object-oriented modelling by using BPMN models and service blueprint	Proposition of Smart-circular PSS Lifecycle Flowchart and service archetypes to select Circular Economy strategies.	Street lighting system
Alix and Zacharewicz, (2021)	Smart Product-Service System: Process Value Model in the Framework 3DCE	Product-service focus	G-DEVS model	Actors and material are described from a qualitative and quantitative point of view	Not reported
Lüttenberg (2020)	PS3 – A Domain-Specific Modelling Language for Platform-Based Smart Service Systems	Product-service focus	Object-oriented modelling	Modelling Language for the conceptual design of platform-based Smart Service Systems.	Storage systems
Chang et al. (2019)	A user-centric smart product-service system development approach: A case study on medication	Product-service focus	Stakeholder network	Proposition of a diagram called "provider integration network," which displays material,	Medication management

	management for the elderly			information, and value flows.	
Liu et al. (2019)	A framework with a hybrid approach to analyse system requirements of smart PSS toward customer needs and co-creative value propositions	Product-service focus	Sequence diagram	Proposition to use a sequence diagram to display interactions between customer and provider and identify co-creative value propositions.	Smart fridge
Maleki et al., (2018b)	Industrial Product-Service System modelling based on Systems Engineering: Application of sensor integration to support smart services	Product-service focus	Object-oriented modelling	Proposition of a method to model the subsystems of a sensor-based PSS offering (product, service, and enabling systems)	Industrial machine
Lee et al., (2019)	A structural service innovation approach for designing smart product-service systems: Case study of smart beauty service	Product-service focus and user-focus	TRIZ and Service blueprint	Generic approach for structural service innovation approach, which integrates the advantage of PSS engineering and service engineering	Cosmetics
Buchmann (2016)	Modeling product-service systems for the Internet of Things: the ComVantage method	Product-service focus	Object-oriented modelling	Modelling approach to requirements representation for collaborative work between business stakeholders and app designers	Mobile maintenance for industrial machines

3.3 PSS modelling techniques from the product-service perspective

These techniques employ conceptual prototypes commonly used in diverse design applications. In the summary of proposed PSS prototypes presented by Ilg et al. (2018), we find conventional graphical representation tools previously mentioned, such as Customer Journey Map, Actor Network Map, Business Model Canvas, Function Model, IDEF0 diagrams, System Maps, and Meta-modelling. These visual tools can be catalogued as conceptual prototypes (Osterwalder et al., 2014). Based on Valencia Cardona et al. (2014) findings, we can infer that applying modelling techniques in the early Smart PSS design phase must aid the design team in two aspects. First, to reduce the design process' complexity and the organisational and intellectual efforts devoted to designing the Smart PSS solution. Second, to visualize the system associated with the Smart PSS solution as a whole, depicting the relations among the system subcomponents.

Medini and Boucher (2019) proposed a method combining conceptual modelling and model-based engineering to address these issues. PSS visualization is at the core of their method with two main aims. First, it generates a holistic and comprehensive understanding of the PSS solution. Second, it enables knowledge elucidation throughout the early design phase (e.g., PSS value proposition structure, PSS

value delivery network configuration, PSS lifecycle, economic model parameters, insights about customer desirability of the PSS value proposition). This method's foundations are further elaborated in the following subsection.

3.4 The contributions of conceptual modelling in PSS and Smart PSS prototyping

Considering the visualization of the system being designed and the provision of insights on this designed system as prototyping key goals in the early design phase, conceptual modelling and Model-Based System Engineering (MBSE) are selected as concepts to be further explored. On the one side, conceptual modelling is defined as *"the activity of formally describing some aspects of the physical and social world around us for purposes of understanding and communication"* (Mylopoulos, 1992). The conceptual modelling application's outcome throughout the design process is a series of iterative models that serve as sketches of the system to be developed. On the other side, MBSE's definition used by Apostolov et al. (2018) was "*an interdisciplinary engineering paradigm propagating the use of formal models instead of documents to support requirements generation, analysis, specification, design, verification and validation of the system under development in the early conceptual phase but also continuing throughout the development and later life cycle phases.*"

Both concepts converge in the creation of models. The basis for developing a model is a modelling language, defined as "*a set of possible models that are conformant with the modelling language abstract syntax, represented by one or more concrete syntaxes and that satisfy a given semantics*" (Da Silva, 2015). The activity consisting of creating modelling languages is called metamodeling. In this activity, the classes belonging to the to-be-designed system and the relationships among these classes are formalized. For example, suppose we wanted to model the business model concept by Osterwalder and Pigneur (2010). In that case, we could define a class called 'value proposition', and create a relationship called 'sold through' that would be linked to another class called 'channel'.

The metamodelling activity's outcome is the definition of the modelling language's structure (e.g., the rules about the classes that can be linked, the subclasses that belong to a class). Modelling languages use graphical notations such as the Unified Modelling Language (UML) and the Business Process Model and Notation (BPMN) to represent the models. These notations are known as the concrete syntax, aiming to establish the rules to create these conceptual models. The literature on PSS and Smart PSS design presents examples of modelling frameworks using different graphical notations. For instance, Shimomura et al. (2009) used the BPMN notation in an extended version of the Service Blueprint, while Apostolov et al. (2018) applied Systems Modeling Language (SysML) in their modelling framework.

Several authors proposed modelling languages tailored to the specificities of the PSS design process. Their works introduce their proposed metamodels as a basis for their PSS modelling approaches. Figure 10 illustrates an example of these resulting metamodels. These metamodels are generally represented by using the UML notation. Table 4 presents part of the meta-modelling approaches proposed to support PSS design. Only two of the works described in Table 4, Medini and Boucher (2019) and Pirola et al.

(2022), report the usage of computer-based tools to implement their modelling approaches in real-life contexts. On this point, Valencia Cardona (2017.p.175) highlighted two aims of these tools. First, these tools must map the system associated with the Smart PSS solution. Second, the supporting conceptual prototyping tools should assist in identifying the value delivery network actors and depicting their roles and contributions.
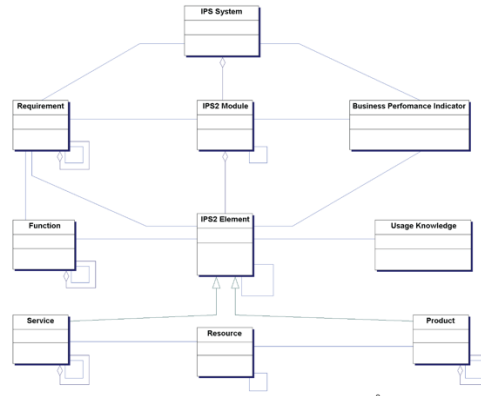
Figure 10. Metadata model for IPS2 lifecycle management (Abramovici et al., 2009).

Table 4. Proposed Meta-modelling approaches for PSS design.

Title and author	Design field		Design focus	Contribution	Case study
	PSS	Smart PSS			
Metadata Reference Model for IPS2 Lifecycle Management (Abramovici et al., 2009)	X		Value co-creation. Seven classes are represented in the metamodel: product, service, resource, usage knowledge, requirements, function, and business performance indicator.	Extended version of Product Lifecycle Management (PLM) approach to cover the industrial product-service system's (IPS²) design needs.	Not reported
PSS Layer Method – Application to Microenergy Systems (Muller et al., 2009)	X		Value co-creation. Nine classes are considered in the metamodel: Needs, values, deliverables, lifecycle activities, actors, core products, periphery, contract, and finance.	Method aimed to define requirements and tasks for the PSS solution development.	Solar Home System
A Metamodel for Product-Service System based on Systems Engineering (Maleki et al., 2018)	X	A case study involving smart services	Value co-creation. Three metamodels are introduced: PSS requirement, the system of interest, and PSS enabling systems.	Metamodel aimed to define a PSS solution. This PSS is divided into two subsystems: System of Interest (SOI) and Enabling Systems (ES).	Industrial machines
Specifying a modelling language for PSS Engineering – A	X		Value co-creation. Classes are grouped into nine modeling views: requirements,	Formal modelling procedure to support PSS design.	Robotic systems for industrial cleaning

development method and an operational tool (Medini and Boucher, 2019)			product, service, demand, offer, activity, organization, performance, and scenario.		and product traceability
Design and Engineering of Product-Service Systems (PSS): TheSEEM Methodology and Modeling Toolkit (Pirola et al.,2022)	X		Value co-creation. Three perspectives grouping classes are included in the metamodel: solution, customer, and process perspectives.	SErvice engineering methodology supported by a modelling toolkit for its implementation.	Automation systems for residential use

The conceptual prototypes generated in this early design phase must be easy to understand, given that the Smart PSS design team is often cross-functional (Valencia Cardona et al., 2014). Thus, the notation used in these models must be intuitive so that the design goals can be clearly communicated, and a common language could emerge within the design team. The supporting conceptual prototyping tools must be focused on generating visual aids to assist practitioners in transitioning from abstract ideas to tangible models (Valencia Cardona, 2017). Consequently, as Osterwalder and Pigneur (2010) argued, visual thinking plays a crucial role in the design of innovative offerings, as is the case in the transition from product-centric to service-based offerings. Visual thinking has been incorporated into the computer-based tools proposed by Medini and Boucher (2019) and Pirola et al. (2022). The models generated in these tools employ pictograms to facilitate the conceptual prototypes' readability and understandability.

As it was argued in section 2.3, from the BMI perspective, practitioners face four main questions during the early design phase (Gassmann et al., 2014): (i) "who are the main target customers?", (ii) "what is offered to customers?", (iii) "how the offerings are produced?", (iv) "how is profit generated?". This design phase's expected outcomes are the customer needs analysis, the value proposition, the value network configuration, and the offering's financial viability analysis. Nonetheless, the concurrent design of the value proposition and value networks associated with Smart PSS offerings and the profit mechanisms have not been addressed in the literature (Murillo Coba et al., 2020; Alix and Zacharewicz, 2021). The following section presents a brief review of prototyping approaches' utilization in PSS and Smart PSS design literature to address value proposition and value network visualization.

3.4.1 The role of conceptual prototyping in PSS and Smart PSS value proposition design

One of the critical questions for a manufacturing company starting the servitization path is what must be offered in the all-inclusive solution, other than the product itself. The process involving the offering's content design, aimed to meet the most important users' needs, is often known as value creation (Garcia Martin et al., 2019). The primary outcome of this value creation process is the value proposition statement, defined as *"the bundle of products and services that create value for a specific customer segment"* (Osterwalder et al., 2014). According to Linde et al. (2020), industrial firms risk "*pushing out*

a digital business model without understanding customer value" in this value creation process. This situation implies that industrial firms might devote resources to developing an offering that does not have enough potential clients, or these clients are not willing to pay for the solution. In this scenario, the offering is doomed to be a commercial failure because of desirability risk mismanagement in the design process.

To avoid this adverse scenario, industrial firms must concentrate on understanding customers' needs (Parida et al., 2019). In this regard, Design Thinking has arisen as a promising approach to collect these needs. In this approach, the need-finding stage provides guidance about extracting needs by conducting in-depth interviews and applying tools such as stakeholder map, customer personas, customer journey, user story, and empathy map. The insights obtained in this customers' needs elicitation stage can be classified into customer jobs, customer pains, and customer gains, as proposed by Osterwalder et al. (2014) in their tool called Value Proposition Canvas (Figure 11), specifically in the section named 'customer profile'. Value Proposition Canvas is a widespread conceptual prototype used in BMI (Osterwalder et al., 2020).

Following the value proposition guidelines by Osterwalder et al. (2014), we consider that the design team is aware that a customer segment buys a product or a service contract to perform an activity or satisfy a need. Thus, the main goal at this stage is to untangle key stakeholders' needs through approaches like Design Thinking (DT). The information collected during the DT application concerning customers' needs to-be-satisfied represents the *customer job* concept. Usually, customers describe negative experiences they face when performing the activities necessary to satisfy their needs. These undesired experiences correspond to the *customer pains* definition. Instead of enduring these negative incidents, customers expect to obtain benefits while performing the jobs required to satisfy their needs. These expectations are linked to *customer gains*. Neuhüttler et al. (2018) presented the applicability of Value Proposition Canvas in the development of smart services for extraction machines. These authors concluded that this tool is well-suited for smart service design in the B2B context.

The Value Proposition (VP) statement is often the outcome of an ideation stage (Osterwalder et al., 2014; Lewrick et al., 2018). Among the tools recommended in the ideation stage by Lewrick et al. (2018), we find brainstorming, dot voting, analogies, and benchmarking as inspiration, and the 6-3-5 method. After the generation of ideas, an evaluation of these ideas is carried out to select the most appropriate ones. The resulting VP statement describes the bundle of products and services that targets the most important customers and key stakeholders' needs.

One of the most significant challenges reported in Smart PSS value proposition design literature concerns the value created for the customer and key stakeholders from the data generated by the digital services (Valencia Cardona et al., 2014; Zambetti et al., 2021; Rapaccini and Adrodegari, 2022). In other words, a Smart PSS Value Proposition can include innovative and state-of-the-art smart products and digital services that generate vast amounts of information for the client. However, there is the risk that customers and other key stakeholders do not appreciate the value of this information and the smartness

of the value proposition. In this situation, customers might find the Smart PSS attractive but not worth paying for, leading to the desirability risk materialization.
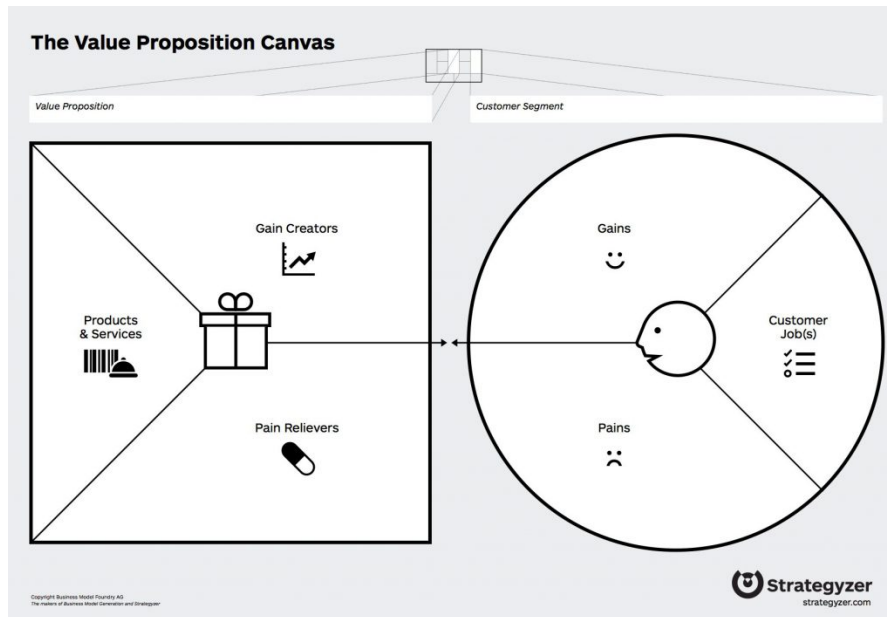
Figure 11. Value Proposition Canvas (Osterwalder et al., 2014).

To assist designers with this desirability risk management, supporting conceptual prototypes aimed at VP design can serve as cognitive support to prompt discussions about the potential risks that might endanger the offering's success. Here, it is essential to note that the information generated throughout the design process (e.g., stakeholders' jobs, pains, and gains) must be stored and shared within the transdisciplinary design team. Hence, tools that can store the models and the critical information originated during the design iterations meet the requirements of the Smart PSS design process. In addition, to assist the digital service technical development, conceptual models must enable the design staff to identify the data required to develop the digital services (Zambetti et al., 2021).

The information generated from the data extracted from sensors must address the customer jobs, gains, and pains of the key stakeholders (Murillo Coba et al., 2020). Otherwise, the Smart PSS VP's desirability is at high risk. An additional aspect concerning Smart PSS value proposition design, derived from the literature, is that the value proposition must evolve over time with the continuous addition of new functionalities through the digital services (Valencia Cardona et al., 2014). For this reason, an iterative and non-linear design logic is paramount for updating the Smart PSS value proposition. Takenada et al. (2016) argued that IoT data from smart appliances are vital to obtaining insights that will serve as an input to update the value proposition. Hence, they highlight the need to pay attention to the data format used to model customer behaviour.

The final elements we consider key in the Smart PSS VP design are extracted from the literature review presented by Da Costa Fernandes et al. (2020). This review addresses the VP design approaches used in PSS in the context of BMI. These authors' findings can be summarised as follows:

    (i)   The VP design process must adopt a systemic and collaborative approach. This process must be integrated with the other value processes (value delivery and value capture). In this regard, Sjödin et al., 2020b presented a framework for the value creation process of outcome-based services that integrates the value capture process into the VP design.

    (ii) Visualisation tools (conceptual prototypes) should be used in the VP design. Hence, the design team must be able to visualize products and services integrated into the Smart PSS VP. Additionally, associations with customer value must be tangible.

    (iii) Smart PSS solution's lifecycle must be considered in the VP (i.e., all the products and services involved during the whole lifecycle must be included in the VP's conceptual prototype).

    (iv) A multi-actor perspective, integrating other stakeholders in addition to the service provider and customer, must be represented in the VP design process.

    (v) Different value dimensions must be contemplated in the VP design process. Orellano et al. (2021) argued that stakeholders' value could be classified into five dimensions: economics, environmental, social, relational, and functional.

Based on the insights obtained from the PSS and Smart PSS literature review concerning VP design, we can elicit the conceptual prototyping requirements mentioned below. These requirements were formulated considering the aims to support the innovation risk anticipation. Thus, in this value creation process, designers must be able to visualize these key aspects:

    (i)   The key stakeholders involved in the product-based value network that might influence the development of a Smart PSS solution integrating the firm's existing products.

    (ii) The targeted customer segment and the potential market size associated with this customer segment.

    (iii) The products and services included in the VP during the whole Smart PSS solution's lifecycle and their links to several value dimensions.

    (iv) The value offering (i.e., how the value proposition will be commercialised, and the associated economic model, which includes the so-called 'value capture' and 'value delivery' processes.)

In addition, designers must be able to collect the information necessary to carry out the Smart PSS simulation performance through the iterative creation of the conceptual prototypes (Alix and Zacharewicz, 2012). A specific modelling language for Smart PSS design is appropriated to create the conceptual prototypes that incorporate the above-mentioned key aspects, based on the findings by Medini and Boucher (2019) and Karagiannis et al. (2022). These conceptual models can be implemented in a computer-based tool that creates conceptual prototypes digitally. These digital prototypes are quick to develop. Therefore, their application in the design process meets the growing agility needs in the BMI process (Muller et al., 2009, Karagiannis et al., 2022). The approaches to assist the Smart PSS design team with the third dimension in the BMI perspective, the value chain to deliver the Smart PSS solution, are presented in the next section.

3.4.2 The role of conceptual prototyping in PSS and Smart PSS value delivery configuration

Once the Smart PSS value proposition has been defined, the main question for practitioners is how to deliver this value proposition to the customer segment. As product-centric industrial firms are habitually specialised in designing, manufacturing, and distributing products, they are expected to lack capabilities in delivering services and creating and implementing digital solutions. Thus, the design team must deliberate about the external actors with complementary capabilities and resources to deliver the Smart PSS value proposition. This mechanism to provide customers with the components of the value proposition is called value delivery (Garcia Martin et al., 2019).

Sketching this extended network of actors in the early PSS design phase has received terms such as value network configuration (Medini and Boucher, 2016) and supply network design (Brax and Visintin, 2017). The expected outcomes in this value delivery prototyping approach are: (i) the depiction of the partnerships necessary to implement the Smart PSS solution and the roles of these partners (e.g., the customer channel, the client of the manufacture), and (ii) the description of the resources and activities involved in the all-inclusive solution delivery. In the context of digital servitization and Smart PSS, the perspective of building a business ecosystem enabled by digital platforms has been addressed by Kamalaldin et al. (2021); Kapoor et al. (2021); Sklyar et al. (2019) and Lenkenhoff et al., (2018).

To illustrate this scenario, consider boiler digital sales platforms like HomeServe in the United Kingdom. In this digital platform, residential gas boiler manufacturers use their products as the platform, defined as *"products, services, or technologies that are similar in some ways, but provide the foundation upon which outside firms (organised as a "business ecosystem") can develop their own complementary products, technologies, or services"* (Gawer and Cusumano, 2014). Gas boiler manufacturers collaborate with a third party that provides customers with all-inclusive quotes for gas boiler purchase and installation. This third-party subcontracts self-employed installers to install the boilers at the customer's home and handles payment facilities with credit providers for the customer to finance the new gas boiler.

The configuration of this network in the early design phase requires characterising the processes involved in the value proposition delivery. These processes are broken down into activities and assigned to critical external actors to define the responsibilities of the network actors. These tasks support crucial activities for implementing the Smart PSS offering, such as defining agreements and contracts with external suppliers and partners. In contract design, the identification of risks arising from the value proposition and the distribution of these risks among the network actors (e.g., who will bear the repair costs in case of product malfunctions, who will pay in case the customer defaults) is decisive to avoid legal disputes once the solution has been implemented in the market (Baines et al., 2020).

The value Network Analysis (Allee, 2008) is the most common tool used to visualise the interactions among the network actors and the win-win relationships. This method requires mapping the network by displaying three elements: actors' roles, transactions, and deliverables (Figure 12). Andriankaja et al. (2018) determined that PSS value network configuration was often poorly or partially addressed in PSS

design methods. To the author's knowledge, value network configuration has been integrated into Smart PSS design frameworks by Liu et al. (2019) and Chang et al. (2019). These scholars employ models that map the actors' network by displaying the information, material, and value flows among them.

The main risk that can arise from this design phase is that the solution provider guarantees the customer gains that cannot be met because of a lack of proper processes to deliver the promised value proposition (Linde et al., 2020). For this reason, practitioners implicated in designing the solution must visualise and understand the value delivery process. The iterative modelling of the value delivery network elements may be pertinent to identifying pitfalls in the planned business ecosystem. These pitfalls belong to the feasibility risk category. For instance, a partner that may not be willing to participate in the network but whose role is key to the Smart PSS solution's success.
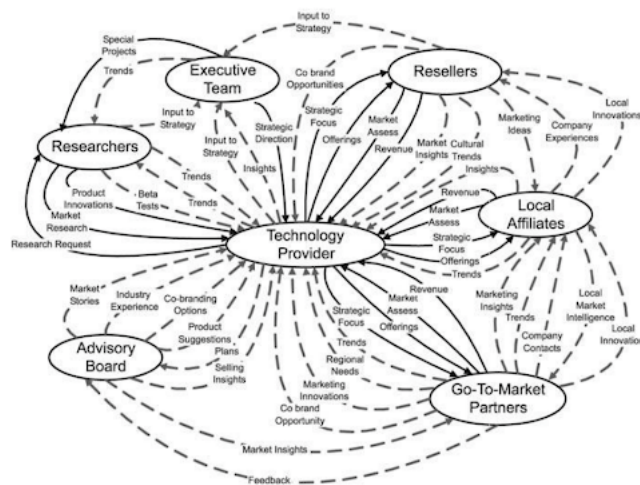
Figure 12. Example of a value network analysis diagram (Allee, 2008).

In Smart PSS design, a particular situation is the need for manufacturing firms to have access to IT-related capabilities such as ensuring the product's connectivity, data analytics, and the design of user interfaces (Parida et al., 2019). Hence, manufacturing firms may rely more on partnerships with new actors compared to the product-centric value chain. These new relationships are a source of uncertainties that may generate risks that lead to the digitalisation paradox (e.g., cost overruns in software development or data transmission). Anticipating and creating mitigation strategies for these risks is crucial to obtaining the expected profits from Smart PSS offerings.

Based on the insights obtained from the literature review, we can note that in the value network configuration phase, the conceptual prototypes associated with the value network visualization must depict the following elements: (i) the stakeholders involved in delivering the solution, (ii) financial transactions, (iii) tangible deliverables, and (iv) intangible deliverables. These conceptual prototypes are helpful for practitioners to trigger discussions about the feasibility risks associated with delivering the service-based value proposition (VP) (Kapoor, 2022).

From the literature review, it can be pointed out that conceptual prototypes inspired by the Value Network Analysis (VNA) tool by Allee (2008) are the most used conceptual prototypes in the PSS

(Kapoor, 2022). In Smart PSS literature, examples of conceptual prototypes that depict the value network without detailing all the elements of the VNA tool are found in Chang et al. (2019) and Kaiser et al. (2021). However, additional conceptual prototypes are needed in the Smart PSS design process to support the process of going from the service-based value proposition to the Smart PSS value network's final prototype. These supporting conceptual prototypes are lacking in the PSS and Smart PSS literature. These intermediate conceptual prototypes are aimed to generate insights to aid Smart PSS designers in (i) the definition of the resources needed for the delivery of the value offering, (ii) the planning of the activities involved in the processes for value delivery, (iii) the selection of external actors having the appropriate capabilities, (iv) the distribution of activities and roles among these actors, (v) the definition of performance indicators that conveys the selected actors' value expectations, (vi) the identification of risks related to the difficulty of building the value network, (vii) the collection of data to assess the Smart PSS offering's financial viability from a multi-actor perspective.

Conclusion

For industrial firms specialising in manufacturing domestic appliances, transitioning from a product-centric mindset to a service-provision perspective implies adjustments in how the value offerings are conceived. First, by extending the scope of the team involved in classical product development to other internal actors apart from product management. Second, the design object changes from a physical product to an all-inclusive value proposition that is a business ecosystem's focal point. This transition from pure products to a bundle of smart products and services enabled by digital technologies represents a Business Model Innovation (BMI) for the manufacturing company. In this BMI process, adjustments in the value proposition, the value network, and the profit mechanism are expected. However, literature on Smart PSS has not addressed the concurrent design of these BMI dimensions. From this same BMI's perspective, the anticipation of innovation risks during the early design phase has not been included either in PSS or Smart PSS design literature.

To answer the question about what tools can be used to support the Smart PSS design, we consider that the prototyping design technique has been recommended in the BMI context. PSS literature has reported its use in PSS design as a design visualization tool for designers. In this regard, it is important to note that the early Smart PSS design phase is characterized by a low Technological Readiness Level in which conceptual prototypes are appropriate to meet designers' needs. Different prototypes may be needed throughout the Smart PSS design phase according to each stage's requirements.

PSS and Smart PSS literature show that generic conceptual prototypes from the design field and modelling languages specific to PSS design have been used as prototype approaches. In this early design phase, designers need tools to conceptualize and visualize the system associated with the Smart PSS. From a business value perspective, two main components that can be conceptually prototyped make up this system: the value proposition and the value network. We find the Business Model Canvas among the 'traditional' conceptual prototypes used in PSS design. However, this prototype does not depict the

interrelationships between the value proposition and value network components. Both components are critical for the offering's success. Therefore, a conceptual prototyping approach specific to Smart PSS is needed to support practitioners in designing the value proposition and the value network associated with the offering. Literature does not address the prototyping of these dimensions simultaneously.

For the development of the proposal presented in Chapter 5, the following elements are retained:

- Prototypes needed in the early Smart PSS design phase must be quick to make, inexpensive, and easy to share. These prototypes must also facilitate iterative loops and enable designers to make abstract concepts tangible. For these reasons, digital prototypes are considered over paper-based prototypes.

- The employment of conceptual prototypes should assist the value proposition design and value network configuration processes. These prototypes must be intuitive and easy to understand, given that the design team is transdisciplinary. Therefore, the notion of visual thinking must be integrated into the conception process of these prototypes.

- The initial design phase's conceptual prototypes must depict the main components of a value proposition and a value network. The utilization of these depictions in the design phase must be aimed to trigger questions about the Smart PSS offering's desirability, feasibility, and viability. For instance, questions such as "do these digital services address the most important customer pain points?", "what data must be captured from the sensors to deliver this digital service?", "do we have access to the resources required to process these data?" should arise from the prototyping sessions in the design loops.

- The conceptual prototyping approach in Smart PSS design must enable the collection of the information necessary to assess the Smart PSS offering's economic viability.

These retained elements are considered to develop the modelling tool presented in Chapter 6 that supports the implementation of the Smart PSS design framework introduced in Chapter 5. Complementary, as an offering's financial viability also requires a quantitative assessment to predict the offering's profitability in terms of monetary profits, the quantitative modelling approaches used in PSS and Smart PSS design are reviewed in the following chapter.

Chapter 4. Economic quantitative evaluation of Smart PSS offerings

Introduction

The fourth dimension of the Business Model Innovation (BMI) perspective concerns the profit mechanism (Figure 4). Two elements are involved in the profit mechanism definition: cost structures and revenue-generating mechanisms (i.e., how the customer will be charged: a fixed periodic fee or a usage-based fee). The critical question to be addressed in this dimension is how to provide decision-makers with evidence about the potential monetary profit that can be generated by selling the offering. The risk of not meeting the firm's financial targets derived from the offering's commercialization is called viability risk, as introduced in section 2.3.

An example of this viability risk is the case of the Autolib offering. This popular electric carsharing offering based in Paris ended its services in 2018. The press reported two causes that led to the end of their service: (i) the high costs associated with the car fleet maintenance and the infrastructure to recharge the vehicles, and (ii) fewer users than expected. These factors made this digital-enabled service unprofitable. In order to avoid such adverse outcomes, Smart PSS design must include an estimation of the costs incurred in service delivery and a projection of the potential revenues. These estimations must consider the uncertainty in the profit mechanism's input parameters (e.g., the number of customers that subscribe to the all-inclusive solution).

Benedettini et al. (2015) established that firms that undertake a servitization strategy are more exposed to bankruptcy risks than those that continue offering products. Although bankruptcy is a highly adverse outcome of a servitization strategy, the inability to obtain substantial financial gains may discourage industrial firms from continuing to provide all-inclusive solutions. To tackle this issue, quantitative assessment methods should be applied in the BMI context to predict the conceptualized offering's profitability (Euchner and Ganguly, 2014). These methods belong to the 'system focus' category proposed by Phumbua and Tjahjono (2012) and are mentioned in section 3.3.

Quantitative assessment methods are not exclusively applied to predict the offering's economic performance. In PSS design literature, these methods have been used to assess other PSS value dimensions such as the environmental impact (Kjaer et al., 2018), customer satisfaction (Kimita et al., 2009), and social impact (Allen Hu et al., 2012). Although sustainable value generation through Smart PSS offerings is on the Smart PSS research agenda (Pirola et al., 2020; Alix and Zacharewicz, 2021), only the economic value dimension is considered in this review.

This chapter is aimed to review the approaches used in the literature to tackle the digitalization paradox in the early design phase. Gebauer et al. (2020) define this as *"a situation in which companies invest in digitalization but struggle to earn the expected revenue growth."* This situation has also been studied in the context of the provision of PSS, where this phenomenon is called the servitization paradox (Brax et al., 2021). In this case, companies that offer PSS offerings fail to meet the financial targets that ensure the firm's viability. This is the type of detrimental scenario that a company like elm.leblanc seeks to avoid when launching an all-inclusive offering enabled by IoT. Considering the above, the question that guided this review was: *what quantitative modelling techniques have been used to predict the offering's profitability in PSS and Smart PSS design?*

The structure of this chapter is as follows: Section 4.1 introduces the definition of the profit mechanism from the BMI perspective. Then, the estimation processes of the two profit mechanisms' components, cost structures, and revenue streams are reviewed from the PSS and Smart PSS design perspectives. Next, section 4.2 presents the quantitative risk and uncertainty management frameworks that have been proposed for both PSS and Smart PSS design contexts. Finally, the simulation approaches to evaluate the performance of the PSS and Smart PSS Business Models are reviewed. The chapter ends with a summary of the elements retained for the proposed design framework presented in Chapter 5.
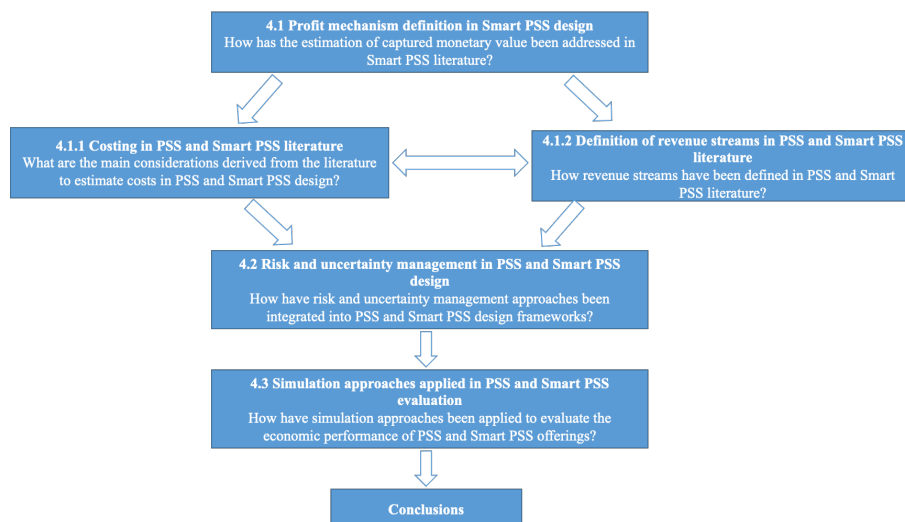
Figure 13. Outline of Chapter 4.

4.1 Profit mechanism definition in Smart PSS design

In the previous chapter, we acknowledged that two main issues arise in the Smart PSS solution design process: what the manufacturing company will offer and how this offering will be delivered to customers. An additional question that emerges in the design phase is whether the offering is profitable for the industrial firm aiming to offer a service-based offering. To answer this question, practitioners estimate the monetary value that may be attained by selling the offering. These estimations require: (i) defining the profit formula, in other words, specifying the cost elements and revenue streams associated with the offering, (ii) making projections of service delivery costs throughout the offering's lifecycle, and (iii) forecasting the market volume based on the customer segment size, (iv) and deciding on the pricing strategy. These activities correspond to the business model's captured value estimation, also known as the project's business case analysis (Garcia Martin et al., 2019).

Further questions arise in the design of Smart PSS offerings. Baines et al. (2020) argue that a business case for digital-enabled and service-oriented offerings can be carried out considering the potential direct value capture and the generation of indirect value for the service provider. The former refers to the fees that are charged to the customer. These fees can be billed periodically, for example, monthly or annually. Usage-based payments can also be implemented (i.e., the number of hours in which the product is used). Here, designers face additional questions to address. For example, concerning who bears the cost of the hardware needed to collect and send the data from the product to the cloud storage represents an additional cost.

These interrogations lead designers to propose alternatives to answer questions such as: should this hardware be sold to the customer in a one-off transaction? Should this hardware be included in the recurring fee? If so, what is the payback period of the option of not charging the customer for this hardware that enables the digital service delivery? Consequently, a method and its supporting tools are needed to evaluate the different alternative scenarios to capture value from the operation of the Smart PSS offering. Concerning the indirect value for the Smart PSS value network actors, this includes aspects such as savings in operational costs (e.g., maintenance operations) and data monetization. For instance, the data collected from customers' premises can be used to improve the efficiency of products and services.

Smart PSS literature has addressed the implications of shifting from one-off sales to a recurring revenue economic model enabled by digital technologies (Linde et al., 2021; Parida et al., 2019). These authors argue that this shift impacts the traditional cost structures, risk management, and revenue streams of the ecosystem actors implicated in delivering the Smart PSS value proposition. As changes occur in the profit formula (revenues and costs) regarding the one-time sale transaction, the main risk is that managers sell and implement the solution without clearly comprehending the revenue and cost drivers' dynamics (Linde et al., 2020). This lack of understanding may eventually lead to the digitalization paradox, defined as the negative economic outcomes resulting from the Smart PSS offering's commercialization.

Based on these insights derived from the literature and considering the multi-stakeholder nature inherent to Smart PSS offerings (Valencia Cardona et al., 2014.; Lenkenhoff et al., 2018), we retain two initial aspects to consider in our proposal. The first one is the need to depict the financial transactions taking place within the value delivery network. The second involves defining the cost objects associated with the offering's lifecycle. The conceptual prototypes employed in the design phase can support these activities. At this initial stage, these representations can enable practitioners to comprehend better the Smart PSS offering's profit formula (Medini and Boucher, 2016).

As previously mentioned, the servitization process is expected to influence the industrial firm's cost structure, revenue stream definition approaches, and risk management practices. The following two subsections review how the profit mechanism's elements, cost structures, and revenue streams have been addressed in the PSS and Smart PSS design literature. Then, section 4.3 reviews the risk management approaches to deal with the economic viability that have been applied in these same design fields.

4.1.1 Costing in PSS and Smart PSS literature

In literature, costing the service-based offering has been highlighted as one of the significant challenges that industrial firms face in their servitization efforts (Rodriguez et al., 2020). This is primarily due to the high presence of uncertainties affecting cost values (Erkoyuncu et al., 2011). In a product-centric context, industrial firms are used to costing their products considering the activities associated with product design, logistic operations, production, and supporting services such as marketing and sales. However, the costing scope in a service-centric context extends to service delivery, product upgrade, disposal, and remanufacturing (Matschewsky et al., 2020).

Depending on the value network actor's roles and the offering's scope, new sources of uncertainty related to service delivery appear. For instance, energy price fluctuations become an uncertainty source for the manufacturer or service provider when the energy price risk (See Figure 6) is transferred from the customer to the manufacturer. Undoubtedly, costs associated with repairs in an all-inclusive offering affect its profitability. For this reason, PSS costing has been a notable research topic in the PSS field (Datta and Roy, 2010).

Rodriguez et al. (2019) conducted a review in PSS costing and found that academic literature has employed different cost estimation frameworks such as Life Cycle Costing (LCC), Through-Life Costing (TLC), Total Cost of Ownership (TCO), Whole Life Costing, and Whole Life Cycle Costing (WLCC). However, these cost estimation frameworks were not conceived for the PSS design specifications. Among these specifications, we find the integration of products, services, and digital services in the offering, contracts with customers that tend to be long-term, and ownership transferred from the customer to the service provider, consequently turning the product into a service provider's asset (Erkoyuncu et al. 2011; Kambanou and Lindahl, 2016). Rodriguez et al. (2019) concluded that a cost estimation paradigm adapted to the PSS context is needed. According to these academics, this paradigm should consider the steps derived from their literature review, namely, (i) definition of cost

estimation viewpoint, (ii) characterization of the cost estimate, (iii) conceptualization of PSS, (iv) computation and assessment of the estimate, and (v) adjustment and definition of the estimated baseline. The step involving the computation and assessment of the estimated cost proposed by Rodriguez et al. (2019) is carried out considering three aims. First, "*to quantify the cost impacts of a given set of parameters' values"* (e.g., how the service costs vary depending on the service frequency, the product's failure rate, and the markup on the service intervention). Second, *"to measure the aleatory uncertainty around the estimate*." Lastly, *"to identify its associated risks"* (e.g., fluctuations in raw material prices, scarcity of skilled staff to conduct the service operations). In addition to the uncertainty in cost estimates, another challenge that designers encounter in the BMI context concerns the lack of historical data to support the cost estimates projections. This can be explained considering the offering's novelty within the firm's operations. To tackle this issue, Farsi et al. (2020) proposed a bottom-up Activity-Based Cost (ABC) estimation to simplify these estimations when data is scarce.

For manufacturing companies that also offer long-established after-sale service contracts, as in the case of elm.leblanc, less uncertainty around the "traditional" services' cost values is present. These companies have experience pricing their contracts to make them profitable and control their operational service costs. For instance, the data collected from the field about their products' breakdown rates aid in predicting the expected number of repairs. Moreover, in the case of domestic appliances, like gas boilers and heat pumps, the main service involved is the mandatory routine maintenance, whose frequency and duration are known. In this case, new cost objects emerge when these companies add new services to their portfolio, like digital services.

For instance, if a remote diagnostic service is added to the firm's value proposition, new costs for the firm must be integrated into the after-sales department's operations. Among these new costs for a manufacturing company, we can mention the investments in software development to deliver the digital service, the hardware to enable the product's connectivity, data transmission and storage, user experience design (UX) consulting to create end-user interfaces, data analytics operations, digital platform-related costs, among others (Chowdhury et al., 2018; Zolnowski et al., 2017; Alix and Zacharewicz, 2021).

Research works exclusively focused on Smart PSS costing remains scarce. The few existing works in this field usually address the service provider's perspective. For example, Osako et al. (2019) presented a method for IoT-enabled PSS adoption, in which they compared the maintenance costs of a PSS and a Smart PSS scenario. From the customer's perspective in the B2C context, it has been reported that the IoT-enabled services' cost for the customer is the most significant barrier to the desirability of these offerings (McKinsey, 2021). Hence, it would be pertinent to assess the cost-benefit ratio from the customer's point of view in this B2C context.

4.1.2 Definition of revenue streams in PSS and Smart PSS literature

As mentioned in Chapter 3, the Smart PSS value proposition is the focal point of a value network. Therefore, this value proposition creates direct captured value for the actors involved in the value delivery network. If the Smart PSS offering does not generate enough monetary value for at least one of the key actors, the offering's feasibility is endangered. For this reason, it is important to visualize the revenue streams for the key actors. Designers can collect the necessary information from this revenue stream representation to formulate the profit equations used in the economic assessment. For example, payment periodicity and cash flows among value network actors are crucial for the viability assessment (an actor's revenue represents a cost for another actor). This payment periodicity depends on the PSS economic model (i.e., product-oriented, use-oriented, and result-oriented) defined in the value proposition design.

Once the profit equations have been formulated, the next step for an economic assessment is gathering the value of the revenue streams' input parameters: price and volume. Pricing strategies in Smart PSS from the digital service provider's perspective were addressed by Leiting et al. (2021). For the actors not involved in the digital service delivery, the most straightforward pricing strategy is to add a markup to the product or service intervention's direct cost. This markup is aimed to cover overheads and enable the actor to make a profit in either the product sale or the service intervention.

Estimating the second revenue stream's input parameter, the market volume entails a higher degree of complexity. This value estimation is linked to demand uncertainty (Erkoyuncu et al., 2011), as industrial decision-makers cannot accurately predict the number of all-inclusive contracts to be sold in a fixed planning horizon. Market volume estimations can be based on customer segment size, competitor analysis, and customer surveys. Yet, these estimations are highly uncertain, and dynamic factors are likely to outdate the estimations during the planning horizon. An overestimated market volume may lead to approving an offering's implementation that, over time, will not meet the financial targets, as was the case with Autolib, presented in this chapter's introduction.

Data monetization is another revenue stream that often emerges from Smart PSS offerings. The data collected from smart products can be sold to other companies (Opresnik and Taisch, 2015). In addition to direct captured value, the indirect captured value that can be easily translated into monetary terms can be integrated into the revenue stream definition. For instance, the efficiency gains that key value network actors can obtain from the Smart PSS operation. Among the examples of these gains, we can mention energy savings, cost reductions in maintenance operations, and increased productivity.

Globally speaking, literature on revenue streams in the Smart PSS field remains scarce. The most comprehensive work is presented by Linde et al. (2021). These authors propose a revenue model design framework for digital services (Figure 14). From the framework presented in this work, we can highlight the following conclusions:

(i)   The revenue frequency should be selected according to the cost structure. For example, if cost flows are recurring, it makes sense to charge the digital service periodically.

(ii)   There must be a win-win relationship between the provider and the customer. Both parties must obtain monetary value from the digital service operation.

(iii)   The provider needs to agree on performance indicators with the customer. For example, the time between detecting a malfunction and the time a technician fixes the problem.

(iv)   Digital service providers need to develop new risk mitigation strategies to cope with the operational risks (e.g., the availability of the heating appliance in a result-oriented contract).

These conclusions were drawn from B2B case studies. The definition of revenue streams for digital services in the B2C context, concretely for smart domestic appliances, is a research perspective (Holgado et al., 2020).
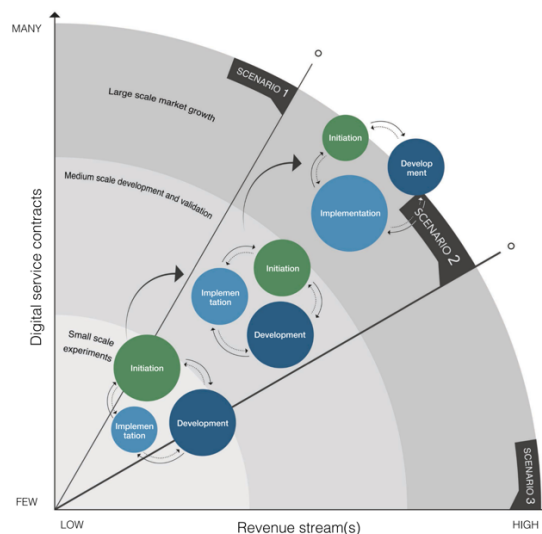
Figure 14. Framework for designing revenue models for digital services (Linde et al., 2021).

4.2 Risk and uncertainty management in PSS and Smart PSS design

Implementing Smart PSS offerings represents new risk sources for industrial firms, mainly originating from the interdependencies in the service delivery network and the high presence of uncertainties (Boucher et al., 2019). Consequently, academics called for developing flexible risk management systems dealing with the increasing uncertainty sources (Parida et al., 2019; Dellermann et al., 2017; Benedettini et al., 2015). This risk management approach should be integrated into the early design phase (Murillo Coba et al., 2020). Here, it is essential to make the distinction between risk and uncertainty.

Uncertainty is defined as "*the difference in the amount of information that is required to perform a task and the amount of information already possessed by the firm*" (Galbraith, 1977). Consequently, uncertainties result from a lack of information in the design phase about future events. These uncertainties may cause the occurrence of undesirable events (risks) or positive events (opportunities). Identifying opportunities is also a part of the standard project risk management approach. In this regard, tools such as the SWOT analysis are often employed to identify opportunities derived from project implementation. However, the scope of this thesis addresses the innovation risks that negatively affect

the monetary value generation for the actors involved in Smart PSS delivery. For this reason, we focus on risk anticipation and control.

As for the definition of risk, Hubbard (2020) conceptualized it as a state of uncertainty where some possibilities involve a loss, injury, catastrophe, or other undesirable outcomes. These adverse events (e.g., overestimated revenues, high maintenance costs, lower market prices for the same solution) can lead to the digitalization paradox, in which the Smart PSS provider fails to capture enough monetary value to meet its financial targets. The development and commercial launch of the Thermibox digital service by elm.leblanc, described in section 2.4.1, is an example of the digitalization paradox's occurrence.

In order to assess the economic performance of the Smart PSS offering, it is necessary to formulate the cost and revenue structures in terms of parameters assigned to the service delivery actors (Medini and Boucher, 2016). These cost and revenue structures form the economic model's equations used to evaluate the offering's financial performance. Economic models' key parameters can be associated with uncertainty factors. For instance, demand uncertainty can be related to annual demand volume when projecting the sales turnover of the Smart PSS solution.

An uncertainty parameter's nature can be random, epistemic, or a combination of both. When an industrial decision-maker observes that an uncertain parameter's value is not expected to change during the planning time horizon, this parameter is entirely epistemic (e.g., a product's lifespan). Suppose decision-makers determine that the current data can be partially used for future events. In that case, the uncertain parameter is considered to have both an epistemic and a random nature (e.g., labour costs). Lastly, if the parameter's uncertain nature cannot be reduced by obtaining more information, then the uncertain parameter has a random nature (e.g., service churn rate, energy price, etc.).

Bearing in mind the possible positive outcomes from uncertainty's presence, Herzog et al. (2014) recommended expanding risk management in PSS design to uncertainty management (Figure 15). These activities have different scopes. According to Kreye (2017), uncertainty management is the ability to reduce the influences of uncertainty. As for risk management, ISO 31000 standard defines it as "*the systematic application of policies, procedures, and practices to the activities of communicating and consulting, establishing the context and assessing, treating, monitoring, reviewing, recording and reporting risk*" (ISO, 2022).

Risk management approaches can be qualitative and quantitative. Erkoyuncu et al. (2015) point out that "*qualitative approaches use subjective scoring techniques, and the quantitative technique covers statistical and probabilistic approaches to quantification*." The qualitative approach is embedded in project management standards, where the project team identifies risks, assigns them a magnitude according to their potential impact, comes up with mitigating strategies to cope with the most important risks, and monitors those risks throughout the project's execution. Concerning the quantitative approach,

the most common example is the application of the Monte Carlo simulation technique (Erkoyuncu et al., 2015).

Parida et al. (2019) advocated the integration of risk management in the design of servitized business models to assure the Smart PSS offering's profitability during the planning horizon. This profitability must represent a win-win situation for all the actors involved, as mentioned by Herzog et al. (2014). Therefore, a multi-actor and value-sharing perspective in the economic assessment is needed. This perspective implies that it is necessary to predict costs and sales revenues from the Smart PSS offering's commercialization for all the value network actors. For this reason, it is essential to employ conceptual prototypes, as argued in Chapter 3, to visualize the financial interactions taking place in the value network and the interdependencies among the value network actors. We retain that the Smart PSS economic assessment must provide decision-makers with quantitative estimates of the revenues and costs for the key actors to calculate their profits. Thus, scenarios leading to the digitalization paradox can be foreseen.
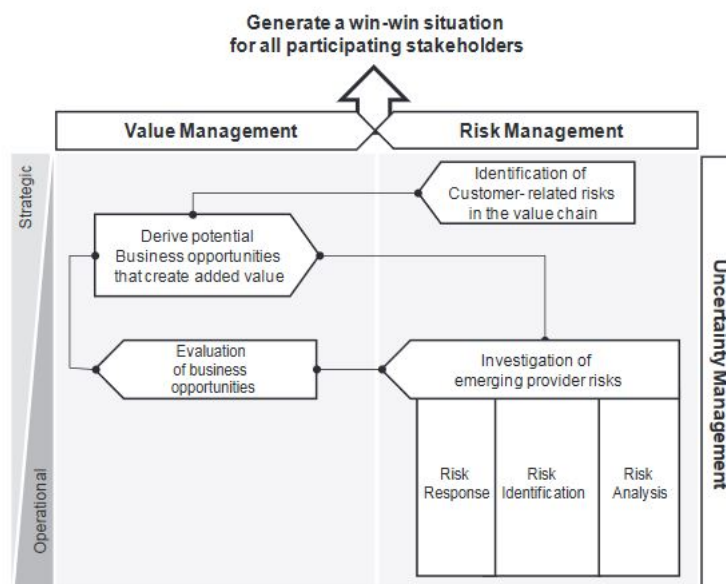
Figure 15. Framework for Risk management in IPS² design (Herzog et al., 2014).

These quantitative predictions will back the decision on whether to make significant investments or not in the Smart PSS offering development (Bilgeri et al., 2015). Determinist techniques like Return on Investment (ROI) are frequently employed to carry out this quantitative prediction. However, in early Smart PSS design, cost drivers linked to service delivery are not well known. Moreover, configuring alternative service delivery scenarios is favoured in this design phase (Anke, 2019). The uncertain nature of key economic parameters requires the employment of stochastic analysis methods in the financial assessment stage rather than determinist methods (Euchner and Ganguly, 2014). Thus, instead of obtaining a single profit value, decision-makers can visualize a distribution of profit values that consider

several combinations of parameter values. This information enables managers to quantify the probability of occurrence of the digitalization paradox.

Refsgaard et al. (2007) listed a set of methods commonly used to assess mathematical models' uncertainty. As profitability analysis relies on mathematical models that describe the actors' revenues and costs, these methods can be applied to evaluate the parameter uncertainty of the Smart PSS economic models. Among the quantitative methods that can be used to deal with parameter uncertainty (i.e., the uncertainty associated with parameter values such as costs), we find error propagation equations, inverse modelling, Monte Carlo analysis, multiple model simulation, scenario analysis, and sensitivity analysis.

In PSS design, Erkoyuncu et al. (2015) proposed a framework for risk quantification for manufacturing and service delivery contexts. These authors presented the classification of risk analysis methods into deterministic, qualitative, and quantitative techniques. The deterministic techniques involve numerical calculation of risk or uncertainty. The qualitative techniques involve employing experts' opinions to identify threats and subjectively score the magnitude of the risk. Lastly, quantitative techniques involve applying statistical and probabilistic approaches to quantification, such as sensitivity analysis, Expected Monetary Value (EMV) analysis, decision tree analysis, and Monte-Carlo simulation.

The main goals of implementing quantitative risk analysis techniques in Smart PSS design are to gauge the balancing of the Smart PSS economic models (Pirola et al., 2020) and identify mitigation strategies for the risks that impact profitability the most (Erkoyuncu et al., 2015). On this matter, Coba et al. (2019) presented an uncertainty quantification aimed at evaluating the economic performance of different PSS economic models and their associated value networks. This framework consists of four steps: identification of uncertainty sources, uncertainty modelling, uncertainty propagation and analysis, uncertainty reduction, and control.

To conclude, from the economic viability perspective, manufacturing firms that undertake the servitization path face two challenges. First, firms need to gather quantitative indications about the added economic value of launching a service-based offering compared to the classical product-centric business model. Second, these firms need to outweigh the economic benefits of establishing a Smart PSS offering compared to a traditional PSS offering. Nonetheless, Smart PSS Design frameworks incorporating the offering's economic viability assessment are lacking in the literature (Pirola et al., 2020). Consequently, computer-based tools that can be implemented in a real-world setting to address the above needs are also scarce in the literature.

These tools are enabled by simulation approaches to support the decision-making process by providing predictions about the value of key economic performance indicators. The simulation approaches used in PSS and Smart PSS design are reviewed in the next section. The proposal presented in chapter 5 aims to integrate this economic performance assessment into the design process. In addition, this proposal integrates quantitative risk approaches into this financial analysis to identify mitigation strategies that may affect the Smart PSS offering's viability. Chapter 6 presents a computer-based tool that supports

the implementation of this assessment and a quantitative risk approach in elm.leblanc's offering design activities.

4.3 Simulation approaches applied in PSS and Smart PSS evaluation

Computing the profits generated by each key value network actor requires formulating the equations representing the costs and revenues incurred by each actor, as presented in Medini and Boucher (2016). These equations can easily be integrated into a simulation platform that computes the actor's profit considering a set of parameters given by the decision-maker. The equations' structures and the value parameters are collected from the insights generated by the conceptual prototypes discussed in Chapter 3. Additionally, simulation approaches enable the implementation of quantitative risk management techniques such as Monte Carlo simulation, scenario analysis, and sensitivity analysis. For these reasons, a computer-based simulation approach is convenient for estimating the Smart PSS economic performance. In the PSS modelling techniques classification proposed by Phumbua and Tjahjono (2012), simulation techniques are grouped under the "system-focus" category. According to these authors, the most common simulation techniques used in PSS design are discrete-event, system dynamics, and agent-based approaches (Table 5). These simulation techniques enable practitioners to visualize the impact of the variation of input parameters on the model's outputs. This is the main reason that makes these techniques appropriate for the economic performance assessment. For example, practitioners can evaluate how the variation of the market volume affects the key actors' profits generated by the Smart PSS offering's commercialization.

Table 5. Definition of the most common simulation techniques used in PSS design.

Simulation technique	Definition
Discrete event	*"The process of codifying the behaviour of a complex system as an ordered sequence of well-defined events. Each event occurs at a particular instant in time and marks a change of state in the system. This is basically used to monitor and predict the behaviour of investments like the stock market, but this tool is now increasingly used to predict the market for industrial goods."* (Kiran, 2019).
System Dynamics	*"System dynamics (SD) is an established discipline to model and simulate complex dynamic systems. The primary goal of SD is to evaluate and design new policies that can impact the system under study in a desired way."* (Schoenenberger, 2021)
Agent-based	*"Agent Based Modelling and Simulation (ABMS) refers to a category of computational models invoking the dynamic actions, reactions, and intercommunication protocols among the agents in a shared environment, in order to evaluate their design and performance and derive insights on their emerging behaviour and properties."* (Abar et al., 2017)

In PSS design literature, academics applied simulation to assess the performance of several possible PSS scenarios and select the most convenient alternative for the solution provider. In the early design phase, a deficient PSS evaluation method may lead managers to implement loss-making PSS service

delivery networks (Nakada et al., 2020). This PSS evaluation can be performed from three different points of view: customer value, sustainability, and trade-offs between perspectives (Qu et al., 2016). Concerning the performance evaluation's scope, scholars have acknowledged sustainable value generation as a core issue in Smart PSS design (Alix and Zacharewicz, 2021; Song et al., 2021; Li et al., 2021; Liu et al., 2020). Consequently, the forecasting of captured value through Smart PSS should aim to cover the economic, environmental, and social dimensions. However, as this thesis seeks to anticipate and mitigate viability risks affecting the Smart PSS value delivery network, only the economic dimension is considered in the performance assessment included in the proposal presented in Chapter 5. PSS performance evaluation literature argues that PSS evaluation can be conducted considering two scopes: the PSS offering and the PSS business model (As seen on the left side of Figure 16). These evaluations are conducted during the early design phase and from a provider's perspective. PSS offering evaluation assesses if the bundle of products and services meets customers' value expectations. In contrast, PSS Business Model (BM) evaluation corroborates if the value derived from the PSS BM is created for stakeholders (Nakada et al., 2020). In the present research project, a BM's performance assessment's scope is included in the proposal from the provider's perspective and a multi-actor perspective.

In Smart PSS design, one of the main issues for practitioners is to demonstrate that the inclusion of digital technology-enabled solutions in their offerings can be monetized (Baines et al., 2020). Moreover, the payment structure that captures value directly from the Smart PSS offering must be delineated (i.e., define if a flat-fee based or a profile-based fee is charged to the customer). The economic performance evaluation must enable decision-makers to compare different alternatives concerning digital service monetization. For example, options considering offering the digital service for free to the customer or requiring recurring payments on different frequencies should be compared.
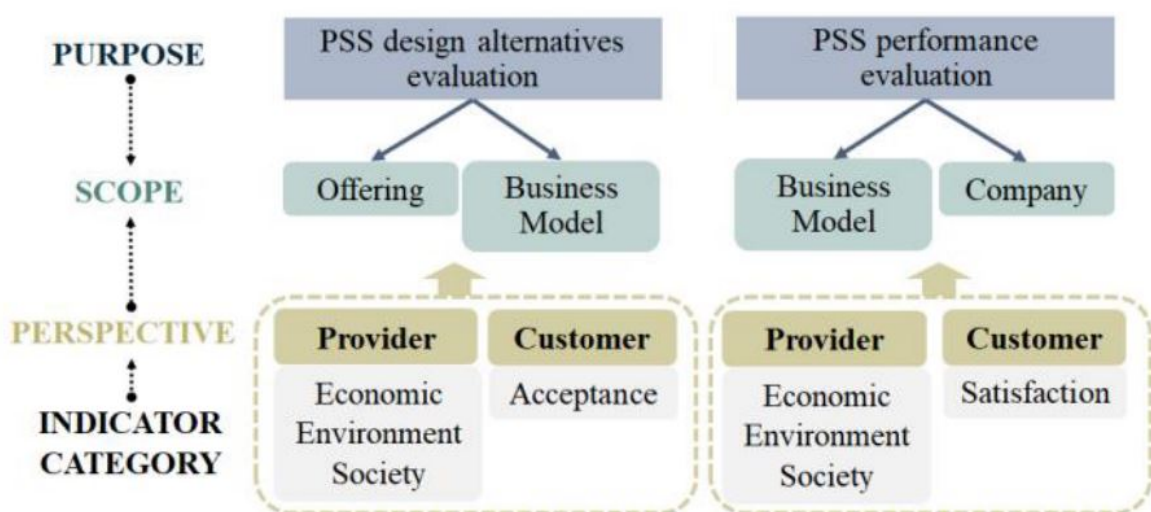
Figure 16. PSS evaluation conceptual framework (Nakada et al., 2020).

Table 6 presents a review of PSS evaluation methods supported by simulation techniques. These research works are classified according to (i) the simulation technique employed, (ii) the simulation

outcomes in terms of performance indicators or metrics, (iii) the multi-actor perspective used, (iv) the economic models simulated, the evaluation scope proposed by Nakada et al. (2020), and the case study application. It is observed that from the economic dimension's perspective, most works focused on computing the total service delivery costs without addressing the uncertainties associated with market volume and pricing strategies. For the most part, simulation approaches are applied in the PSS design phase to evaluate several service delivery scenarios embedded in the classic PSS economic models described by Tukker (2004): product-oriented, use-oriented, and result-oriented. These evaluations' outcome is the selection of the most economically viable service delivery network(s).

Most of the existing PSS evaluation methods have two principal aims. First, they aim to determine if the PSS business model creates value for the actors in terms of profits and calculate the expected delivery costs. By doing so, managers may mitigate the viability risk by (i) avoiding the deployment of an unprofitable service delivery network, (ii) adjusting the cost structure, (iii) exploring new revenue streams, or (iv) exploring new value network configurations. However, these evaluation methods always consider a dyadic (customer - solution provider) or a triadic level of analysis (customer-manufacturer-third party, see Table 6 below). Conversely, the multi-stakeholder level of analysis is acknowledged as a key characteristic of the Smart PSS concept (Valencia Cardona et al., 2014).

Second, another predominant evaluation scope is customer satisfaction (Carlander et al., 2016; Wrasse et al., 2015; Pezzotta et al., 2015; Chalal et al., 2015). These evaluations are carried out by estimating KPIs such as service operation time, the customer satisfaction rate for service delivery, and waiting time. These estimations aim to forecast the required service capacity to deliver the PSS offering. Therefore, these customer satisfaction performance indicators may support managers in mitigating the feasibility risk by avoiding the engagement to provide value offerings without the appropriate service capacity (e.g., resource utilization). For instance, the number of service engineers and heating appliance installers could be predicted if our work's focus was resource capacity planning. Additionally, no Business Model performance evaluation methods dedicated solely to Smart PSS were found in the literature.

In both scopes, the dynamic factors defined by Phumbua and Tjahjono (2012) as *"disturbances, perturbations or even reactions that may affect the performance of the PSS businesses and impose risks on them"* must be incorporated in the evaluation. These authors cite as examples of dynamic factors, product failures, customer loyalty, market changes, the interaction between actors, and price and logistic cost sensitivity. These dynamic factors are evidently present in the heating appliance business as there are factors such as customer payment default and the influence of policymakers' decisions on the sale of certain heating technologies. Undoubtedly, these factors may affect the offering's profitability during the planning horizon. Thus, these dynamic factors must be identified during the mathematical formulation of the economic models to be simulated.

Finally, most of the simulation-based evaluation methods are presented in the B2B context with industrial solutions. A few research works deal with service-oriented offerings, including consumer goods such as toys (Alix and Zacharewicz, 2012), bikes (Estrada et al., 2017), and solar home systems

(Wrasse et al., 2015). Yet, no research has addressed the economic performance evaluation of offerings combining domestic appliances and digital services in the B2C context. In this regard, Smart PSS economic models for these appliances is a topic that is receiving increasing interest from scholars and manufacturers (Holgado et al., 2020).

Regarding risk quantification integrated into the simulation-based approaches for economic evaluation, scholars applied Monte-Carlo simulation methods to acquire a probability distribution of a variable of interest, such as service delivery costs (Kyösti and Reed, 2015; Erkoyuncu et al., 2013) and PSS provider's profits (Boucher et al., 2019). This specific method enables decision-makers to calculate the variable of interest's variability and then examine the probability of obtaining a range of the variable of interest. For instance, managers can determine the likelihood of gaining a specific profitability level. Based on these results, they can decide to act on the pricing, compare it with the customer's willingness to pay, or modify the cost structure to attain the desired financial performance target. Besides, sensitivity analysis enables practitioners to identify the economic model parameters that most impact the variable of interest (de Rocquigny et al., 2008). Then, based on the specified parameters, they can formulate mitigation strategies to reduce the negative impact of the uncertain parameters on the variable of interest (e.g., profit expectations).

Table 6. PSS evaluation methods supported by simulation techniques.

Research Work	Simulation technique	Outcomes of the Simulation / Key Performance Indicators (KPIs)	Economic multi-actor view	Alternative scenarios compared	Scope of the evaluation	Application
Farsi and Erkoyuncu (2021)	Agent-based	- PSS contract cost - Total benefit of contract cost	No	-Inclusive spare part (product-oriented) -Availability-based contract (use-oriented)	PSS design alternatives evaluation (PSS business model)	Machine tool
Boucher et al. (2019)	Monte-Carlo simulation methods.	-Sales revenue - Profit	- Robotic solution manufacturing company - Battery manufacturing company. -Meat transformation company.	- Product-oriented - Use-oriented - Result-oriented	PSS design alternatives evaluation (PSS business model)	Industrial cleaning robotic solution
Bertoni and Bertoni (2020)	Monte-Carlo simulation methods.	- Life cycle cost of the PSS offer	No	Use-oriented	PSS design alternatives evaluation (PSS business model)	Aerospace component manufacturer
Estrada et al. (2017)	Discrete Event Simulation	- Average Cost per Trip	No	Use-oriented	PSS design alternatives evaluation (PSS business model)	Bike-Sharing PSS
Rodrigues et al. (2017)	System dynamics	- Reputation and brand equity - Revenue	No	Not reported	PSS design alternatives evaluation (PSS business model)	Theoretical
Medini and Boucher (2016)	Deterministic simulation	- Total costs - Total benefits - Profit	-Manufacturer - Intermediate actor - Smelter	- Product-oriented - Use-oriented - Result-oriented	PSS design alternatives evaluation	Sludge treatment

				(PSS business model)	
Carlander et al. (2016)	Monte -Carlo simulation methods.	- Total cost service - Denial of service delay (minutes)	No	Product-oriented (maintenance service)	PSS design alternatives evaluation (PSS business model) and PSS performance (customer satisfaction)	Rail industry
Kyösti and Reed (2015)	Discrete Event Simulation	- Overall expected cost and distribution of service support costs	No	Result-oriented	PSS design alternatives evaluation (PSS business model)	Not specified
Wrasse et al. (2015)	Agent-based	- Customers' dissatisfaction index - Labour cost - Profit	No	Product-oriented	PSS design alternatives evaluation (PSS business model) and PSS performance (customer satisfaction)	Solar home systems
Pezzotta et al. (2015)	Discrete Event Simulation	- Customer value: total time spent by the truck in the workshop. - Operational Time and waiting time. - Service provision efficiency, evaluated in terms of cost (both busy and idle costs) and resource utilization.	No	Product-oriented: quick maintenance program and long-term maintenance program	PSS design alternatives evaluation (PSS business model) and PSS performance (customer satisfaction)	Truck company
Chalal et al. (2015)	Discrete Event Simulation	- Satisfaction rate for purchase demands - Satisfaction rate for service delivery - Mean reaction time in maintenance/installation - Average number of delays in maintenance/installation - Overall workload per type of competence - Average level for end-product inventory - Number of stock shortages	No	Use-oriented	PSS performance (customer satisfaction)	Washing machine manufacturing
Alfian et al. (2014)	Discrete Event Simulation	- Profit per day - Acceptance ratio - Utilization ratio	No	Use-oriented	PSS design alternatives evaluation (PSS business model) and PSS performance (customer satisfaction)	Carsharing reservation

Erkoyuncu et al. (2013)	Monte-Carlo simulation	- PSS total cost	No	Use-oriented: three different scenarios	PSS design alternatives evaluation (PSS business model)	- Aircraft carrier industry - Naval industry
Alix and Zacharewicz (2012)	Discrete Event Simulation	- Total revenue sales - Environnemental impact	- Clients - Producers - Sellers (mentioned but not reported)	- Product-oriented - Use-oriented	PSS design alternatives evaluation (PSS business model and PSS offering)	Toy industry
Kim et al. (2012)	Petri Net for discrete event systems	- Service cost	No	Product-oriented	PSS design alternatives evaluation (PSS business model)	Elevator
Erkoyuncu et al. (2011)	Agent-based	- Total cost	No	Use- oriented	PSS design alternatives evaluation (PSS business model)	Naval industry

Conclusion

Even if a Smart PSS offering is compelling to customers and the value network's implementation around this value proposition is feasible, practitioners must secure this offering's financial viability. Thus, profitability modelling becomes critical in designing service-based offerings (Sjödin et al., 2020b). This activity is challenging in the design phase as there is no historical data about the demand for all-inclusive solutions. Moreover, new revenue streams for the manufacturer may emerge during the operation phase of the Smart PSS lifecycle. Furthermore, sales revenue projections are difficult to evaluate. Likewise, the cost structure is extended from the manufacturing and distribution activities to the whole all-inclusive offering's lifecycle. In this context, profitability modelling must be broadened to all the service delivery actors as each one needs to answer the question, "what is in it for me?"

Another critical aspect is the characterization of the economic model's uncertain economic parameters. These parameters play a pivotal role in cash flow prediction in the manufacturer's planning horizon since their variability may significantly impact the cumulative profits obtained from the Smart PSS offering. Given all this, profitability analysis considering uncertainty in input parameters becomes essential in the Smart PSS design process. Especially in domestic appliance manufacturing, where digital services benefits are challenging to communicate to the client in monetary terms (Holgado et al., 2020), unlike the industrial equipment context, where value can be demonstrated; for example, from the prevention of downtimes and efficiency in customers' industrial operations.

The elements we retain from the literature for the proposal presented in Chapter 5 are:

-   During the design phase, practitioners must answer the question, "how does the Smart PSS offering produce monetary value for the focal firm and key stakeholders?". To do so, computer-based tools must support the implementation of the economic performance evaluation method.
-   The supporting computer-based tool must be able to enable the evaluation of several alternatives. For instance, scenarios involving PSS and Smart PSS offerings under different

economic models should be compared to select the best option(s) from the profitability point of view.

- Economic performance assessment in Smart PSS design must be carried out from a multi-actor perspective where win-win situations for all the value network actors involved are key to securing the service delivery implementation.

- Quantitative risk approaches must be integrated into the economic evaluation. This is aimed to identify the economic model's uncertain parameters (also referred to as dynamic factors) that have the most considerable impact on profit expectations. This outcome is used as the basis to define risk mitigation strategies in case the offering provides evidence of profitability.

The proposal to tackle the research gaps identified (Figure 17) and elm.leblanc's industrial needs is presented in the following chapter. The supporting tools intended to facilitate the proposal's implementation in elm.leblanc's practices are described in Chapter 6.

Research gaps derived from the literature review conducted in Chapter 2 and 3	Research gaps derived from the literature review conducted in Chapter 4
- Going from a product-centric to a service-based value proposition implies a Business Model Innovation, since at least two of these dimensions are modified: targeted customer segments, value proposition, value network, and profit mechanism. However, design frameworks that address concurrently these dimensions are lacking in the literature. - Risk management approaches to anticipate innovation risks (desirability, feasibility, and viability risks) have not been included in Smart PSS design. - Low-resolution prototypes adapted to the Smart PSS design concept, from a business value perspective, are needed. - In the Smart PSS context, computer-based tools that generate digital prototypes aimed to assist simultaneously with the value proposition design and the value network configuration are scarce.	- Economic performance evaluation from a multi-actor perspective has rarely been presented in literature, despite the network-based nature of Smart PSS offerings. - Most of the literature has focused on cost estimation without addressing profit estimation. - Dynamic factors such as market volatility must be considered in the economic performance evaluation. - Quantitative risk management approaches aimed to identify viability risk mitigation strategies are needed. - Economic performance assessment of Smart PSS offerings including domestic appliances in the B2C context have not been presented in the literature. - Comparison of the economic performance of PSS and Smart PSS offerings to assist decision-makers has rarely been presented in literature.

Figure 17. Overview of identified research gaps.

Chapter 5. Proposal of a methodological framework for risk-oriented Smart PSS design: sPS²Risk

Introduction

The theoretical background on which this proposal is based was presented in the previous chapters. This proposal is aimed to address the gaps summarized in Figure 17 and elm.leblanc's industrial needs, collected during multiple workshops. These needs concern the creation of a compelling offering, the assurance of this offering's financial viability, and the identification, evaluation, and monitoring of the major risks associated with the new offering. A novel Smart PSS design framework called sPS²Risk was built to address these industrial needs and the gaps found in the literature (Figure 18). The sPS²Risk framework integrates the elements retained from the literature related to Smart PSS design from a business value perspective and performance evaluation to propose a systematic design framework.

A significant element retained from the literature is that the transition from a product-centric to a service-based offering has been addressed from the Business Model Innovation lenses (BMI) (Frank et al.,2019; Paiola and Gebauer, 2020). Considering these lenses, the proposal consisting of a closed-loop, iterative, and incremental design framework, is aimed to tackle a primary gap derived from the literature. This gap regards the lack of design approaches in Smart PSS that concurrently address the four dimensions of the Business Model Innovation process proposed by Gassman et al., 2014 (Alix and Zacharewicz. 2021; Murillo Coba et al., 2020). These dimensions are the customer target selection, the value

proposition, the value network, and the profit mechanism definition. The proposal comprises a preceding 'strategic contextualization' stage and five methodological blocks. These methodological blocks are referenced with letters, from A to E (Figure 18). The proposal is subdivided into two iteration loops: the iterative design and validation loops.

The iterative design loop includes the three first methodological blocks, from A to C. The first methodological block is called '*elicitation of stakeholders' value expectations*' and is aimed to collect and analyse stakeholders' needs. Next, the methodological block B, called '*prototype of general value concept,*' aims to support the service-based and digital-enabled value proposition's conceptual design. Then, the methodological block C, '*specification of the detailed value concept*,' aims to conceptually prototype the alternative value networks to deliver the service-based and digital-enabled value proposition.

The validation iterative loop contains the two remaining methodological blocks. The fourth methodological block, referenced as 'D' and called *'simulation and decision-making applied to the Smart PSS delivery scenarios*,' aims to evaluate the designed Smart PSS offering's economic performance. The last methodological block, called '*development and experimental prototyping of the Smart PSS solution,*' aims to support the creation of a Minimum Viable Product (MVP) and a Minimum Viable Ecosystem (MVE). These outcomes are aimed to be tested with users in real-life scenarios.

The main characteristics of this design framework are addressed in the next section. Each methodological block contains a list of step-by-step tasks detailed in this chapter. The tools developed to support this framework's application are detailed in chapter 6. The validation of this proposal through an industrial case study is addressed in Chapter 7.
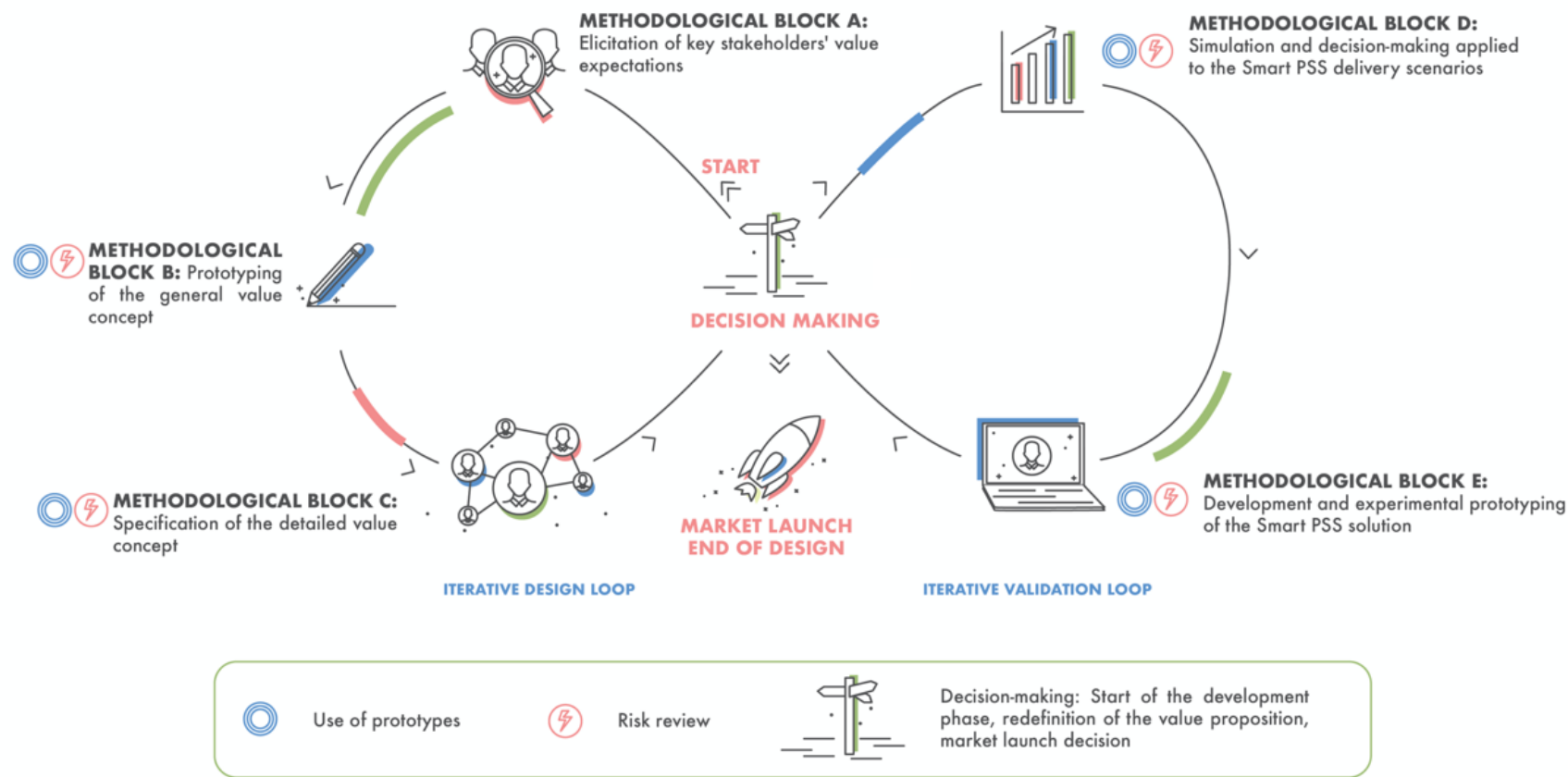
Figure 18. Overview of the sPS²Risk Framework

5.1 Overview of the sPS²Risk framework

This framework was built to serve as methodological support for elm.leblanc in its servitization strategy. Currently, elm.leblanc has an after-sales service, through which the company sells maintenance contracts directly to end-users, as introduced in section 2.4. Nonetheless, this manufacturer has not offered contracts, including a heating appliance and maintenance service, in the past. Thus, the design of these all-inclusive offerings is new to the company's activities. The sPS²Risk framework was designed to address this challenge by providing a systematic design process for service-based value offerings. The starting point of this framework is the firm's existing products and service catalogue. Therefore, the framework does not cover the technical development of products.

Three main aspects are integrated into this framework: a value-driven design perspective, an agile development mindset, and a risk-oriented approach. The first aspect supports the value co-creation process, precisely three of the stages mentioned by Liu et al. (2019). These value co-creation stages named by these authors are: (i) co-exist the value flow of stakeholders, (ii) co-design the value proposition, and (iii) co-implement the interactive value. The other two aspects concern the development of the system associated with the Smart PSS offering: the incremental and iterative construction of this system while reducing the risk of launching a commercial offering that does not meet the profitability targets.

Different departments of a manufacturing firm are involved in designing such all-inclusive offerings. For this reason, this proposal considers the members of a cross-functional team as users of the design framework. The sPS²Risk framework is a structured and systematic approach aimed at guiding this transdisciplinary team. Nevertheless, this framework is not contemplated to be a rigid step-by-step methodology. Instead, the sPS²Risk framework aims to support this transdisciplinary team by providing methods and tools to make well-informed decisions. These decisions concern the four Business Model Innovation dimensions previously mentioned in this chapter.

The sPS²Risk framework's leading goals are to aid in the configuration of the Smart PSS value offering and then to support the decision-making process concerning the selection of alternative Smart PSS economic models to be implemented in the market (i.e., product-, use-, and result-oriented). Once the most critical desirability, feasibility, and viability risks have been controlled, designers can decide whether to implement either a PSS or Smart PSS offering, neither offering, or both types of offerings simultaneously. This offering will be delivered through a specific economic model, or several economic models may be co-existing to deliver the offering. For example, after applying the sPS²Risk framework, designers may hypothetically decide to simultaneously launch a PSS product-oriented and a Smart PSS use-oriented offering.

The sPS²Risk framework's application is supported by computer-based tools introduced in the following sections (notably section 5.1.2) and further described in Chapter 6. From the BMI dimensions' perspective, the sPS²Risk application aid the cross-functional design team in:

(i)   Selecting the target customer segment for which the Smart PSS offering is designed.

(ii)   Supporting the definition of the Smart PSS value proposition and the value offering (i.e., the contract with the customer under a specific economic model).

(iii)   Determining the alignment between the Smart PSS value proposition and customer and key stakeholders' needs.

(iv)   Configuring alternative value network scenarios to deliver the Smart PSS value proposition in which key activities such as marketing, distribution channels, customer interfaces, and digital service delivery are allocated to key stakeholders.

(v)   Evaluating and comparing the financial viability of the alternative Smart PSS value network scenarios from the key stakeholders' perspective.

(vi)   Anticipating the most critical innovation risks that endanger the implementation of the Smart PSS offering and supporting the design of risk mitigation strategies.

5.1.1 Methodological foundations

The sPS²Risk framework was inspired by the Incremental Commitment Spiral Model (ICSM) principles that Boehm et al. (2014) proposed to formulate a systematic design approach. These principles are stakeholder value-based guidance, incremental commitment and accountability, concurrent multidiscipline engineering, and evidence-and risk-based decisions. Three methodological foundations for the proposed design framework were derived from these principles:

1. **Iterative and incremental design loops.** As shown in Figure 18, this framework adopts a closed-loop design logic to cope with the low-structured, uncertain, and evolving 'value requirements' from customers and stakeholders. The main goal of this design logic is to reduce the odds of fully developing an unappalling, unfeasible, or loss-making Smart PSS offering. Thus, an agile approach is adopted in this proposal. This agile approach quickly reacts to unforeseen situations that could threaten stakeholders' value.

2. **Iterative prototyping**. Second, Figure 18 also highlights prototyping's core role. The different prototyping approaches employed in this framework are further detailed in Table 7 (conceptual modelling, experimental prototyping, profitability modelling). Prototyping suits the agile method development by providing a flexible design technique to handle the Smart PSS' dynamic requirements, foster creativity, and facilitate communication within the interdisciplinary design team. Moreover, prototyping is a crucial support for the verification and validation stages. As observed in Figure 18, verification and validation activities are conducted from blocks B to E. In these stages, prototypes are intended to be a thought-provoking tool that represents key

information and stimulates insights generation that examines the Smart PSS idea's desirability, feasibility, and viability.

3. **Progressive identification and characterisation of innovation risks all along the design process**. The third framework's foundation is risk management activities integrated into the design process. Figure 18 shows that risk management tasks are performed across the design framework from blocks B to E. This approach complements traditional qualitative risk management activities employed in project management with a quantitative assessment of financial risks. In this risk-oriented regard, prototyping is also expected to support risk identification as a visualisation tool to prompt discussions about the possible events that would affect the Smart PSS solution's success. Then, based on this information, decision-makers may decide whether to continue with the development process or adjust the envisioned Smart PSS concept.

Table 7. Complementary prototyping types aimed at supporting the design process.

Prototyping Type	Methodological blocks	General principles for each prototyping type.
Conceptual Prototype	*B and C*	*Principles:* generate a structured and graphical representation of design knowledge, which could be shared among multiple stakeholders of the design process. This visualisation aims to facilitate a common understanding of all the components and aspects of the design. It brings the confrontation and convergence among various points of view.
Virtualisation and Simulation Prototype	*D*	*Principles:* (i) to build a virtual model of a partial or whole lifecycle of the Smart PSS and (ii) to simulate the dynamics of this lifecycle in the context of a virtual population of users/customers. The objective is to provide industrial-makers with a Decision-Support System based on the quantitative evaluation of uncertainty impacts on a set of KPIs, helping to decide the best option among the various potential implementation scenarios of the Smart PSS delivery process.
Experimental Prototype	*E*	*Principles:* (i) implement a real draft version of both product and service assets contributing to the Smart PSS offer, and (ii) test the Smart PSS concept with a limited set of key users. The experimentation includes supporting performance analysis and feedback loops to make it possible to integrate improvement actions within the solution.

The main inputs, outputs, controls, and mechanisms of the methodological blocks articulated in the sPS²Risk framework are summarised in Figure 19 as an IDEF0 diagram. These five methodological blocks are:

- Methodological block A: Elicitation of stakeholders' value expectations
- Methodological block B: Prototype of the general value concept
- Methodological block C: Specification of the detailed value concept
- Methodological block D: Simulation and decision-making applied to the Smart PSS delivery scenarios
- Methodological block E: Development and experimental prototyping of the Smart PSS solution

These methodological blocks will be further detailed in sections 5.3 to 5.7.

5.1.2 Supporting tools to implement the framework in an industrial setting

The sPS²Risk framework is a methodological proposal that integrates the elements retained from the literature and adapted to the Smart PSS design from a business value perspective. This framework was conceived to address a set of gaps identified in the literature. These gaps notably concern the conceptual prototyping of two BMI dimensions (value proposition and value network) and the economic performance evaluation of the designed Smart PSS value network.

In order to facilitate the application of the sPS²Risk framework in elm.leblanc's activities, a toolset was defined to support the implementation of the proposal's methodological blocks. This toolset comprises a set of widespread tools in the design field and two computer-based tools explicitly developed for sPS²Risk's deployment. These IT tools are called sPS²Modeller and sPS²Simulator. The former is a modelling toolkit aimed to provide designers with digital models. The latter is a tool that estimates the profitability of alternative Smart PSS value networks.

The sPS²Modeller generates digital prototypes that are quick and easy to create, inexpensive, and shareable. This IT tool enables design team members to store these conceptual prototypes and track changes digitally. Conceptual prototypes that address the value proposition design and the value network configuration simultaneously in the design approach are lacking in the literature. Moreover, these conceptual models employ the visual thinking technique to serve as cognitive support to identify innovation risks during the early design phase.

The sPS²Simulator provides practitioners with estimations of key economic performance indicators associated with alternative Smart PSS value delivery networks. This economic assessment simulator tool aims to assist decision-makers with selecting the most financially promising Smart PSS offering(s). In this regard, the literature lacks frameworks that evaluate the economic added value of Smart PSS offerings compared to PSS offerings under different economic models. Moreover, dynamic factors that

affect the profitability outcome are considered in this economic assessment. Both computer-based tools are further detailed in Chapter 6.

In the following sections, the employment of these tools in each methodological block is addressed. The sPS²Modeller' utilization starts in the 'strategic contextualization' step. Here, the modelling toolkit is used to represent the manufacturer's current business ecosystem. Then, traditional Design Thinking tools are employed in the methodological block A. Next, the sPS²Modeller is used to implement the methodological blocks B and C. Here, the modelling tool supports the value proposition design and value network configuration processes. Subsequently, the sPS²Simulator is used in the methodological block D to provide evidence about the profitability of the designed Smart PSS offering. This economic evaluation is carried out considering alternative value delivery configurations. Finally, the methodological block E advocates the employment of prototyping approaches such as Minimum Viable Product (MVP) and Minimum Viable Ecosystem (MVE) to test the Smart PSS offering with end-users.

5.2 Strategic contextualization

We recommend carrying out a strategic contextualisation evaluation as a preceding step to the application of the proposal presented in this chapter. This evaluation generally involves applying SWOT and PESTEL analysis and elaborating the stakeholder map(s) associated with customer segment(s) (Lewrick et al., 2020, p.83). The outcomes of this strategic contextualisation are:

(i)   A first identification of the external risks (or adaptability risks as coined by Osterwalder et al., 2020) that could threaten the servitization efforts (e.g., regulations, new technologies, macro-economic context).

(ii)   The industrial firm's 'needs' to pursue the servitization path.

(iii)   The targeted customer segment(s) by the service-based strategy.

(iv)   The key stakeholder of the current business ecosystem, which is represented on the sPS²Modeller, specifically on the 'ecosystem modelling view' (further detailed in Chapter 6).

Once the strategic contextualisation evaluation is carried out, the proposal's methodological blocks are applied. Henceforth, the sPS²Risk framework embraces Design Thinking's microcycle to collect stakeholders' needs, devise a Smart PSS value offering, and test a prototype with potential clients (Lewrick et al., 2018, p. 40-43). The first three methodological blocks of the proposal are included in the 'iterative design loop' (Figure 18). Each of the methodological blocks shown in Figure 18 is broken down into tasks (Figure 19). These tasks are described in the following sections.
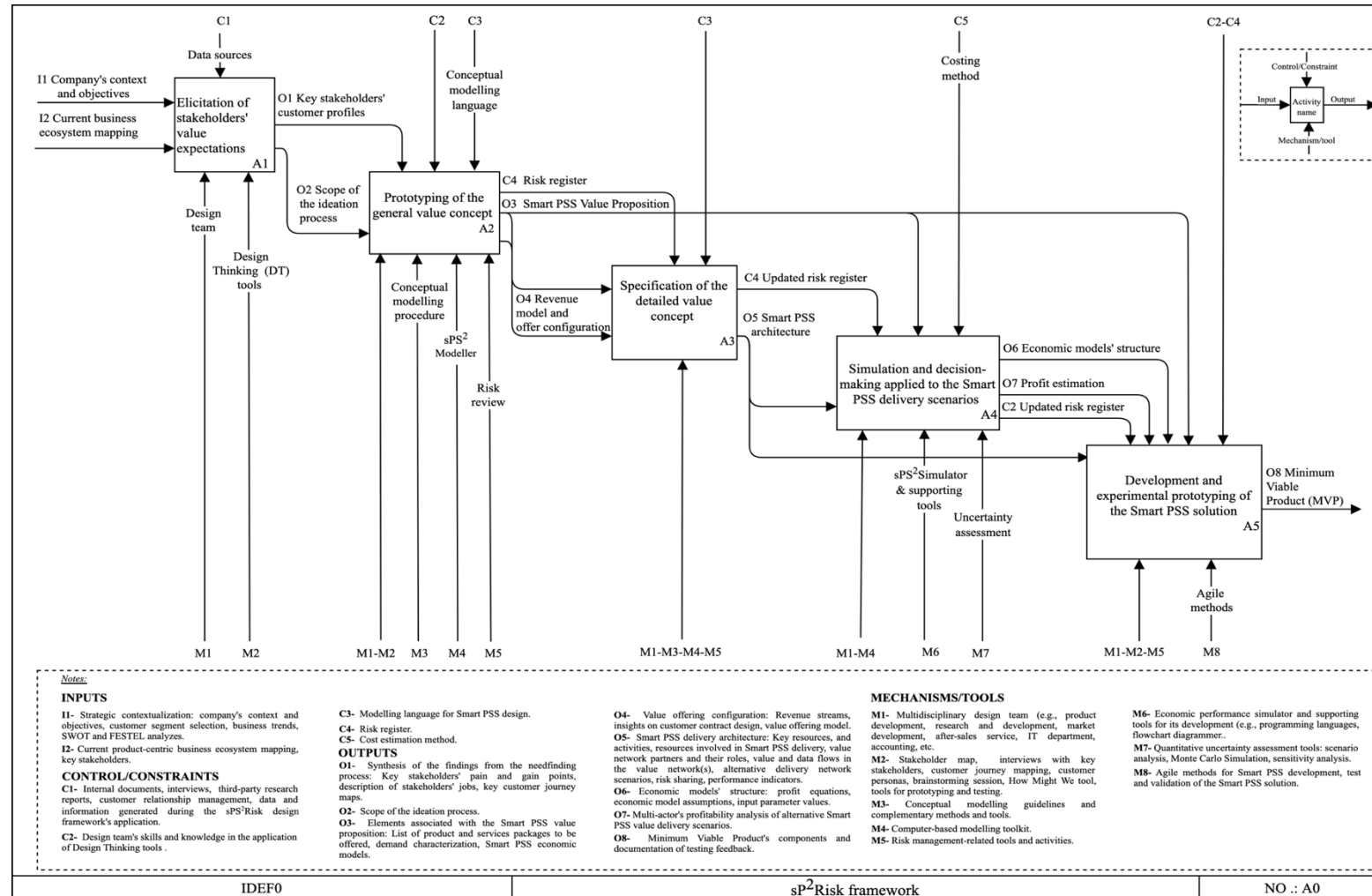
Figure 19. sP²Risk framework's methodological blocks

5.3 Methodological block A- Elicitation of key stakeholders' value expectations

This section describes the internal tasks incorporated in the methodological block A (Figure 20), referenced as A1 in Figure 19. This methodological block is aimed to collect insights about the most important customer and key stakeholder's needs. Most of the tools employed in the following tasks are well-established tools from the Design Thinking and Value Proposition Canvas literature. These tools are not further detailed in this thesis. Further descriptions of these tools can be found in Lewrick et al. (2018; 2020) and Osterwalder et al. (2014). As Smart PSS offerings create value for a set of stakeholders (Valencia Cardona et al., 2014; Kuhlenkötter et al., 2017), an in-depth understanding of their value expectations is fundamental in the design process. Thus, the need-finding process's scope is extended to other key stakeholders in addition to the customer.
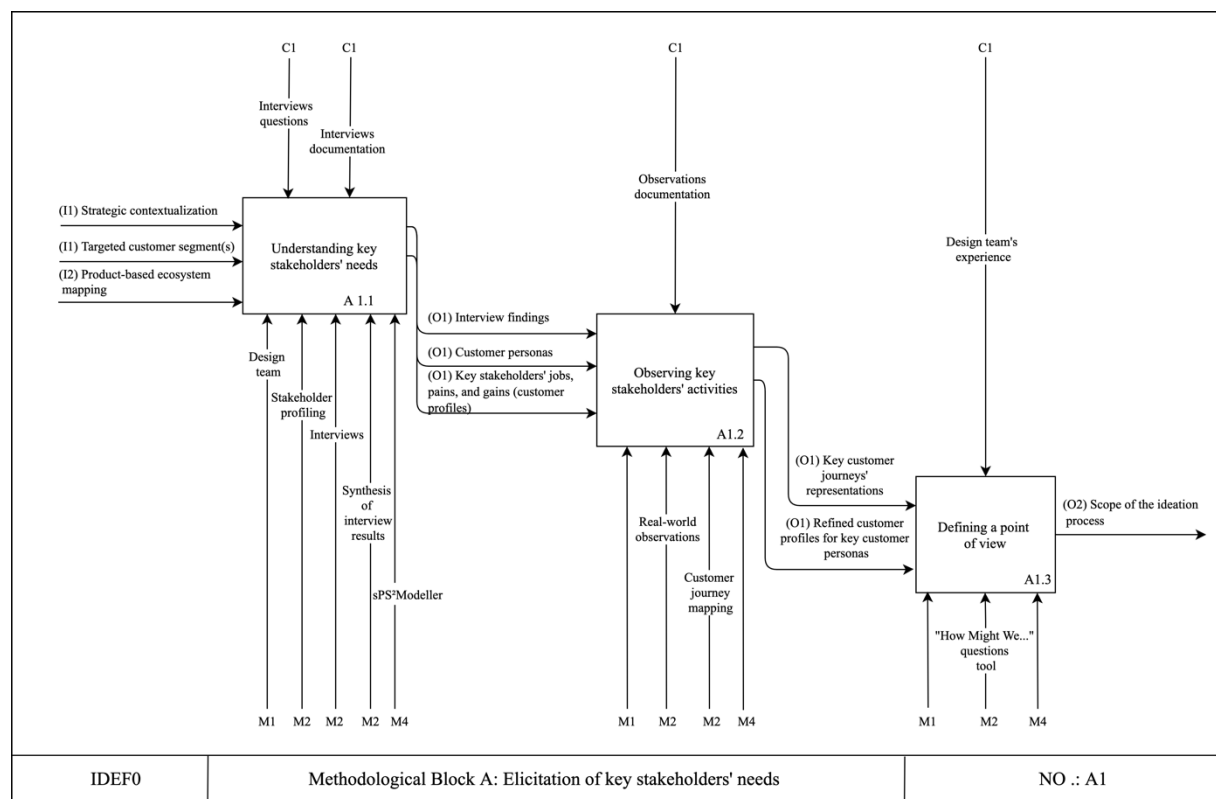
Figure 20. Internal breakdown for the methodological block A- Elicitation of key stakeholders' needs.

Task A1.1: Understanding key stakeholders' needs.

Based on the initial input provided by the preceding contextualisation strategy stage, key stakeholders' value expectations are collected. This step involves conducting interviews with these stakeholders (e.g., customers and critical business partners). These interviews aim to understand customers' expectations of the existing product's functionalities and stakeholders' expectations within the product-based value network. The insights obtained from these interviews are then used to define customer personas (Lewrick et al., 2018, p. 26) for these key stakeholders.

The key findings from the interviews and the established customer personas are stored in the sPS²Modeller to be accessible to the design team. Given that important design information is generated in the methodological block A, the sPS²Modeller was conceived to serve simultaneously as a knowledge repository and a modelling toolkit. Thus, key design information is shareable. Further details about these tools' functionalities are presented in chapter 6. Next, interview findings are converted into customer jobs, gains, and pains and assigned to the key customer personas (Osterwalder et al., 2014, p. 14-17). This list is called 'customer profile' by Osterwalder et al. (2014, p.10-23). The key customer personas are the stakeholders' profiles targeted by the design team.

The main outcomes of this task, grouped as 'O1' in Figures 5.2 and 5.3, and that are stored on the sPS²Modeller are: (i) the interview findings, (ii) the list of customer personas developed based on these findings, (iii) and the 'customer profiles' for each key stakeholder (represented by the customer personas). This last list, also known as 'customer profile,' is derived from the design team's interview results and internal discussions.

Task A1.2: Observing key stakeholders.

After understanding stakeholders' needs, the design team may notice that specific points tend to be often expressed multiple times in the interview results. At this point, it is worth taking a closer look to understand the stakeholders' experiences related to the persistent points mentioned by the interviewees. Here, direct contact with stakeholders to observe their usage context/work environment is crucial.

Customer journey is a convenient tool for mapping these practical usage experiences and elucidating the different usage contexts (Lewrick et al., 2020, p.103). This mapping will enable the design team to better integrate the value-in-use aspect into the value offering design. The final customer journey representations are stored in the sPS²Modeller. Based on these representations, the collected data, and a deep understanding of key stakeholders, the design team must select the most critical 'customer jobs, gains, and pains associated with the 'personas' defined in the task A1.1. This selection is conducted following the Value Proposition Design's guidelines by Osterwalder et al. (2014, p.21).

The primary outcomes of this task that are stored on the sPS²Modeller are: (i) the customer journey mappings resulting from the observation stage and (ii) the refined 'customer profile' for each key stakeholder associated with the previously defined customer personas. These outcomes lay the groundwork for the ideation task (See section 5.4) and are grouped under the 'O1' reference in Figure 19.

Task A1.3: Defining a point of view.

This task is based on the third phase of the Design Thinking micro cycle (Figure 8). This task aims to synthetize the findings obtained from the application of the preceding tasks and establish a common knowledge base (Lewrick et al., 2018. p.41). This common knowledge base is what is known as the

point of view, which guides the conduction of the ideation task (B2.1). In order to carry out this task, the "how might we" (HMW) question tool (Lewrick et al., 2020. p.125-128) is applied. This tool aims to bridge the gap between the stakeholders' jobs, gains, and pains established on the insights collected in the previous tasks and the ideation process for the new value proposition. Therefore, thanks to this tool, practitioners involved in this design process can know the goal of the ideation task concretely. In other words, the problem that must be addressed by the Smart PSS value proposition. In this regard, the HMW tool synthesizes the findings of the understanding and observation phases. This tool's outcome is a set of questions in the HMW format stored in the sPS²Modeller. These questions are aimed to define the scope of the methodological block B's first task, the ideation process (Figure 21). Additionally, this HMW tool guides the design team about the needs that should be met with the designed Smart PSS value proposition.

To conclude the description of this methodological block, it is necessary to mention that the tools presented in this methodological block were selected based on their ease of implementation. This choice was made considering that the practitioners of the industrial firm that collaborated on this thesis were familiar with these tools. These tools are employed in other design contexts within the firm. However, there is a relatively wide range of available tools to meet the objectives of this methodological block. These tools are presented by Lewrick et al. (2020). Practitioners may consider that a specific design process context might require applying additional tools. Then, this methodological block is open to employing additional tools to execute the same tasks, depending on the operational context and practices of the industrial user.

5.4 Methodological block B- Prototyping of the general value concept

This section describes the tasks included in the abovementioned methodological block. These tasks are aimed to support the Smart PSS value proposition design. In this methodological block, the sPS²Modeller plays a pivotal role by providing digital conceptual prototypes. These prototypes support the definition of products and services included in the value proposition, the visualization of the demand associated with this value proposition, and the value offering. Here, we adopt the definition of value offering by Sjodin et al. (2020.p.171), "*A more detailed specification of how value is to be created and delivered to customers* ."In other words, the definition of the economic model through which the contract with the client will be marketed. Figure 21 depicts the tasks involved in this methodological block.

Task B2.1: Ideation.

The cross-functional design team effectuates a brainstorming session, starting from the "How Might We" questions formulated in the previous methodological block. In this session, design team members propose ideas to address the elements of each key stakeholder's 'customer profile' (i.e., the most critical customer jobs, customer gains, and customer pains previously identified). This session's expected output is the product and service (digital and non-digital) list included in the Smart PSS offering's lifecycle.

Osterwalder et al. (2014, p.120-142) suggest guidelines to narrow the number of ideas resulting from the creativity session. These refined ideas will shape the service-based value proposition.

Additionally, the potential economic models for commercialising the Smart PSS solution (i.e., the traditional product-, use-, or result-oriented contracts from the PSS paradigm) are an outcome of this brainstorming session. Here, it is important to question whether the digital services brainstormed truly address important customer jobs, gain and pain points and create value for the key stakeholders. This implies that adding smartness to a product does not necessarily mean creating value for the customer. Therefore, the desirability of the value proposition elements must be discussed and then verified. For instance, let us consider that one of the most recurring pain points identified in the previous methodological block, from the end-user perspective, was the energy cost associated with heating. Then, if the brainstormed elements of the value proposition do not address this pain point, the value proposition must be refined.
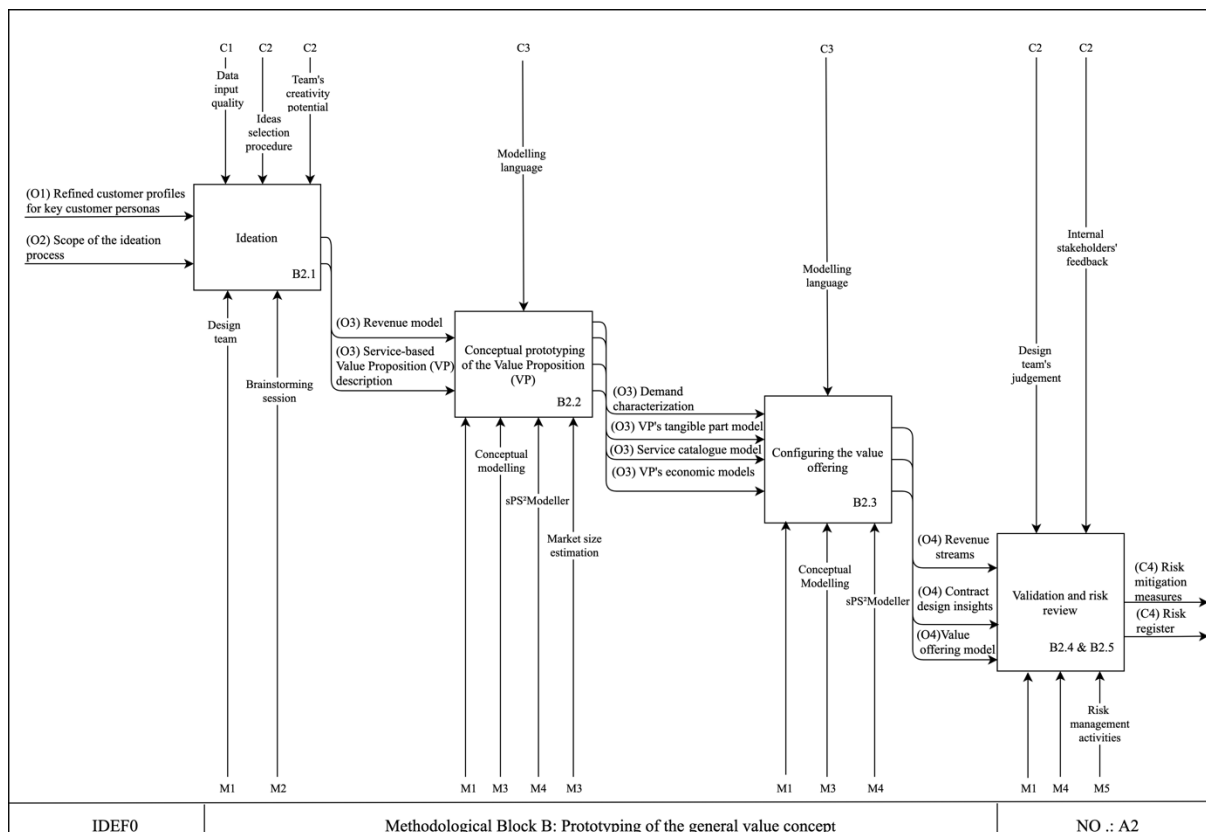
Figure 21. Internal breakdown for the methodological block B- Prototyping of the general value concept.

Task B2.2: Conceptual prototyping of the value proposition.

The outcomes of the ideation task are represented and stored in the sPS²Modeller. The physical part of the Smart PSS value proposition is modelled in the 'product modelling view,' while the basic and digital services are modelled in the 'service modelling view .'These resulting models are referenced as O3 in Figure 21. Here, sPS²Modeller is aimed to represent and gather key information for the value proposition

definition. This conceptual prototyping of the value proposition enables designers to define the requirements of data inputs, technologies, and other resources to deliver the Smart PSS offering.

For example, let us assume that the remote maintenance service for a heating appliance is included in the Smart PSS value proposition. Then, designers must identify the technical means to deliver this service (e.g., secure connection via the cloud, implementation of self-learning and defect detection algorithms), the data requirements (e.g., the temperature in the domestic water tank, compressor time of operation), and the associated technologies to make this service a reality (e.g., the use of sensors to establish breakdown scenarios, the use of smartphone apps to guide the end-user to fix the breakdown). The conceptual prototypes generated by sPS²Modeller are aimed to be cognitive support to identify these types of key knowledge for the design process.

In addition to the value proposition elements (product and services), the customer segment(s) targeted by the value proposition must be characterised by the estimated market share. Moreover, key qualitative information such as different usage contexts is included in this demand characterization. Thus, this activity gives designers an initial notion of the potential value captured through the service-based offering. This activity is carried out by creating a conceptual model in the 'demand modelling view' of the sPS²Modeller. The resulting model is part of the outcome referenced as O3 in Figure 19.

Task B2.3: Configuring the value offering.

The economic models proposed in the ideation task (referenced as *B2.1* in this section) to sell the Smart PSS value proposition are used as a starting point to draft several alternative offering configurations (e.g., pay-per-use offerings, use-oriented contracts). We call 'offering configurations' a combination of products, services, customer characteristics, and usage contexts under different economic models. For instance, if the value proposition concerns the pure Heat-as-a-Service value proposition, designers face the question of how to commercialize this offering in the market.

Special attention must be paid to the monetary value captured from the digital service. The alternative payment frequencies must be defined in this task. For example, taking the remote maintenance service example, the question of whether this service should be charged as an add-on included for free in the offering must be addressed. For this purpose, the 'service contracts' between the Smart PSS provider and its customers can be prototyped thanks to the support of the sPS²Modeller, specifically by using the 'offer modelling view.'

In this modelling view, the 'service contracts' are associated with the 'demand,' the target customer segment, and the economic model(s) defined in the ideation task (i.e., product-, use-, and result-oriented). In these 'offer' models, alternative bundles of products and 'service packages' are prototyped and discussed. Consequently, this offering configuration process provides graphical models to support

the contract design process by facilitating the collection of the Smart PSS offering's key economic attributes (e.g., costs associated with service activities and the tangible part of the value proposition).

In addition, the graphical models of sPS²Modeller guide the designers in outlining the key responsibilities and agreement terms between the Smart PSS provider and the customer. Additional subjects may be inferred from these models and discussed by the design team, for instance, the types of operational risks that affect the value proposition's scope (e.g., product failure, adverse customer behaviour).

Task B2.4: Validation.

In this task, the sPS²Modeller plays once again an important role as support for interactions with the stakeholders during the offering configurations. The service-based value proposition content is checked with internal actors close to key stakeholders, such as product managers and sales representatives. This validation is conducted using the graphical models mentioned in the previous tasks, which are used as a support tool for collaborative knowledge sharing. The aim is to discuss, based on their expertise, whether the service-based value proposition truly targets important stakeholders' jobs, gain, and pain points. Based on this validation, arrangements to interact with stakeholders ought to be made. These encounters aim at obtaining evidence about stakeholders' interest in the modelled value proposition and customers' willingness to pay.

Task B2.5: Risk review.

As observed in Figure 18, risk management activities are conducted in block B. This task is applied routinely in the following methodological blocks. This risk-oriented principle indicates that risks (and their originating uncertainty sources) are identified progressively based on the cross-functional team's expertise and experience. These identified risks are recorded in a *risk register* (Figure 22). This register describes each identified risk, and its format was inspired by the ISO 31000 guidelines (ISO, 2022). This register is stored and shared on the sPS²Modeller so that design team members can add any new risks they identify.

Risk Identification				Risk Assessment					Risk Handling				Controlling
Threat (negative risk) Description	Innovation Risk Category	Entry Date	Update Date	Impact description	Impact (initial)	Probability (initial)	Initial Risk Index	Response Strategy	Measures	Owner	Due Date	Current Status	Status

Figure 22. Risk register.

A risk review is carried out as soon as the methodological block's tasks have been completed. In this review, the identified risks are evaluated and prioritised (See Figure 22). The estimated likelihood and impact of each risk are recorded in the risk register. Subsequently, each risk's score is calculated and added to the risk register. Next, risks are prioritised based on this impact scoring and the design team's judgment on the threats to business value posed by each risk. Other factors that intervene in this risk prioritisation are detailed by Moran (2014, p. 51).

The resulting scoring is expressed as a risk index that depicts its impact on a firm's financial health or image. Then risks can be classified as too high, high but addressable, acceptable, and negligible. Based on this risk index, a response strategy is established for the most important risks (accept, reduce, transfer, avoid). If the risks are considered too high, the design team may consider two options. First, adjust the servitization strategy scope. For example, they may decide to address another customer segment or other pain points. Second, they might decide to stop pursuing the Smart PSS development.

The design team must specify the actions to tackle all other risks. These actions are assigned to members of the design team. In this regard, Bland and Osterwalder (2019) suggest an assortment of tools that can be applied to obtain additional evidence on the value offering's desirability, feasibility, or viability to tackle these risks. These new pieces of evidence will be used to reassess the risk prioritised in a previous design iteration.
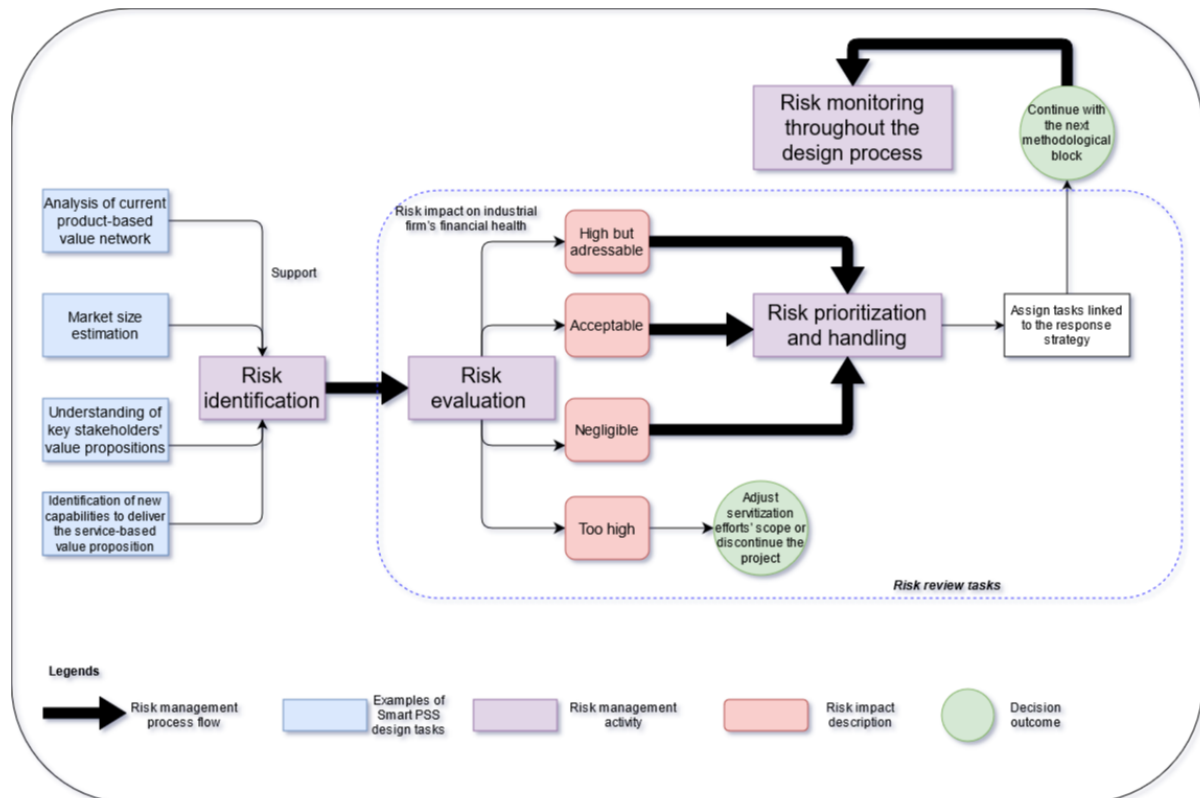
Figure 23. Risk management process illustration.

The outcomes of this methodological block that are stored on the sPS²Modeller are: (i) the value proposition's tangible part model, the service catalogue model, the demand characterization, referenced as O3 in Figure 19, (ii) the value offering model(s), referenced as O4 in Figure 19, (iii) and the risk register referenced as C4.

5.5 Methodological block C- Specification of the detailed value concept

This methodological block starts with a quick risk monitoring review to track the risks prioritised in the previous block. This first risk monitoring review is aimed to reassess risk impacts based on the response actions to tackle the risks. For instance, the design team can find evidence that competitors' service-based offerings were removed due to low demand. This finding may encourage the design team to reformulate the Smart PSS value proposition. If the residual risks remain acceptable, the next methodological block's tasks are performed. These tasks are aimed at configuring the potential value delivery scenarios.

This block's tasks include mapping the roles, responsibilities, and interactions among the service delivery actors. This network configuration process will give a more accurate view of the Smart PSS value delivery actors' cost and revenue mechanisms. To this end, the value network design methodology presented in Kage et al. (2016) was adapted to this block. The 'innovation pull' value network design approach was considered in this work as methodological block C's starting point is the service-based value proposition defined in methodological block B.
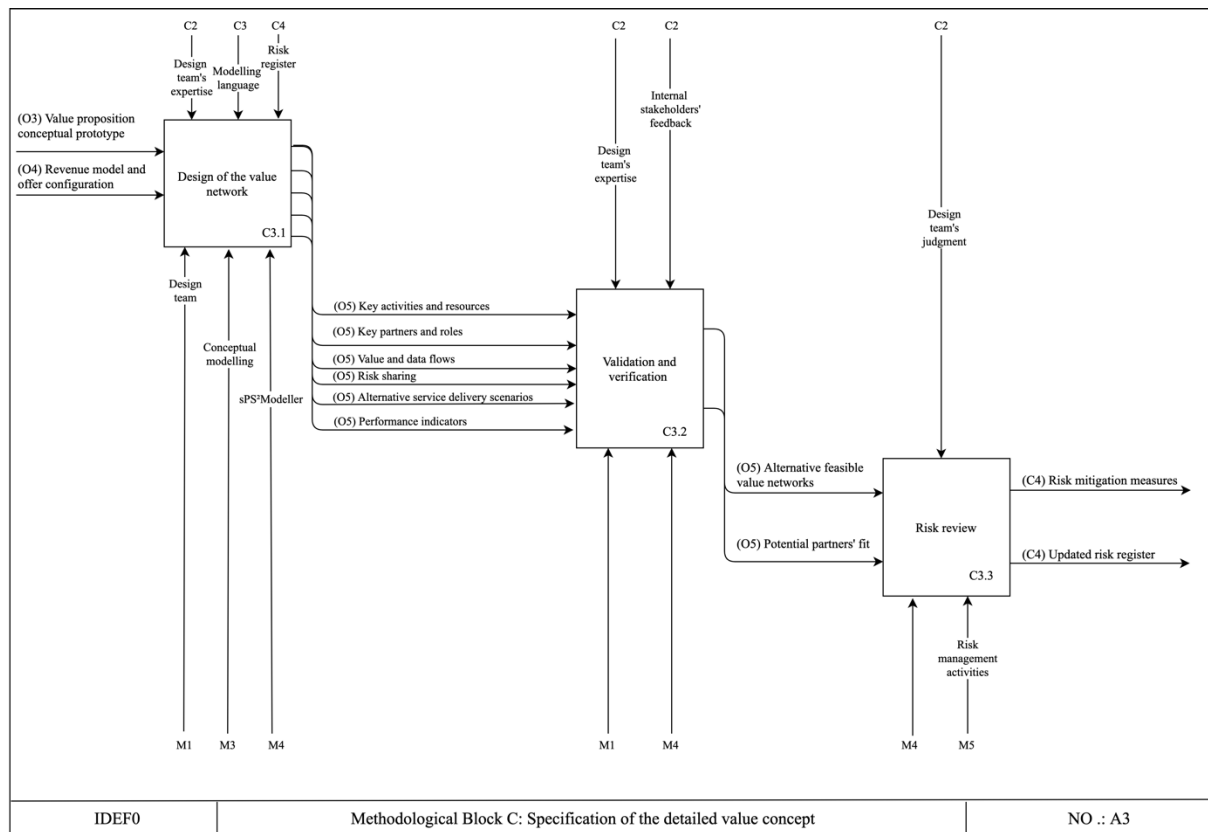
Figure 24. Internal breakdown for the methodological block C-Specification of the detailed value concept.

Task C3.1: Design of the value network.

This task's inputs are the conceptual prototypes of the value proposition elements, which are stored on the sPS²Modeller. The questions covered in this task are depicted in Figure 25. The design team collaboratively and iteratively answers these interrogations. In addition, the sPS²Modeller is employed once again to represent and record the insights obtained in this task. Specifically, the IT tool's modelling views 'activity', 'organisation,' 'performance,' 'scenario,' and 'value network' are employed in this task, in that order. The use of these modelling views in this task is further detailed in Chapter 6. These resulting models are grouped under the reference 'O5' in Figure 19.Key issues such as product ownership, revenue model, partner selection process, information sharing, and collected data ownership are intended to be handled and questioned throughout this block's tasks.

The conceptual prototypes developed with the support of the modelling tool are conceived to initiate these discussions during this methodological block's application. For example, in this task, the industrial firm must evaluate whether it has the digitalization capabilities to deliver the Smart PSS value proposition. Sjödin et al. (2016) define these capabilities as "*advanced abilities to use smart and connected physical products and data analytics to facilitate development and delivery of service offerings*." Let us take the remote maintenance example to illustrate this task's scope. Here, the manufacturer would need to identify the actor that can provide the connection via the cloud to deliver this digital service.
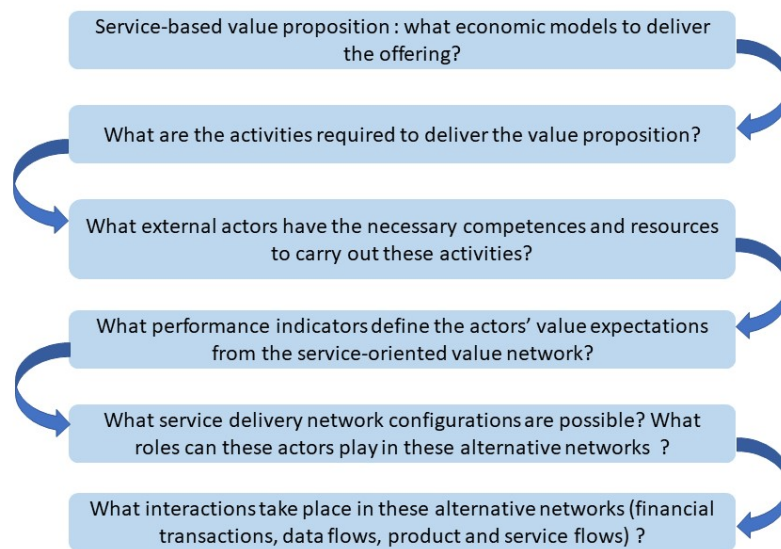
Figure 25. Value network design adapted from Kage et al. (2016).

The last question displayed in Figure 25 is handled through a value network mapping (Allee, 2008). The planned value network's value streams and data flows are displayed in this mapping performed in the 'value network modelling view' of the sPS²Modeller. A notion of the win-win relationships among the network actors is derived from this mapping analysis. This benefit notion is crucial for the implementation of the service delivery network.

Efficient knowledge-sharing management is key to successful Smart PSS delivery. For instance, if a third party sells the 'Smart PSS' service contracts, the manufacturer needs a continuous exchange with this third party to obtain feedback from end-users to improve the digital service experience. Additionally, as 'network management capabilities' are required for the successful delivery of Smart PSS offerings (Sjödin et al., 2016), this conceptual prototype is aimed to enable knowledge sharing visualisation.

Another important aspect is the role of knowledge sharing in planning the resources required to deliver the Smart PSS offering. For example, the number of Smart PSS service contracts sold by a third party in a specific geographical area determines the number of service engineers and installers required in that specific area to ensure the proper Smart PSS service delivery. Then, continuous information exchange must exist between the Smart PSS provider, the maintenance provider, and the installer network. In sum, this methodological block's resulting design knowledge aims to provide the basis to develop the required contractual relationships to deliver the Smart PSS offering. Based on this knowledge, the industrial firm might also consider investing in the development of some new in-house activities.

Task C3.2: Validation and verification.

The potential firms or institutions that can play the roles depicted in the alternative value network scenarios are listed. Then, internal actors associated with partnership development and those with vast

knowledge of the industrial firm's landscape corroborate the potential partner profiles. In this corroboration, potential partners' competencies are examined to determine if they genuinely provide the key activities, customer channels, or technologies to deliver the service-based solution.

This corroboration ought to be through interviews with these potential key partners. Other criteria to be verified are potential partners' financial status, organisational fit with the industrial firm, and respect for the industrial firm's code of conduct (Kage et al., 2016). An additional important criterion in Smart PSS delivery is the partners' digitalization capabilities. For instance, the potential partners' IT infrastructure aimed to exchange information and knowledge must be verified (e.g., information systems compatibility). In this regard, information flows are drafted with the support of the sPS²Modeller. This representation is aimed to guide the assessment of the technical feasibility of these information flows in the value network. In addition, from the focal firm's side, it is crucial to verify that their competencies and resources are pertinent to proposing a partnership with the required business partners.

The sPS²Modeller supports this task by collecting information associated with the potential actors' roles and capabilities. The conceptual porotypes generated by the modelling tool serve as a validation tool. Thus, the potential actors can validate their implication in the delivery network by using the graphical representations generated by sPS²Modeller.

Task C3.3: Risk review.

The conceptual prototypes generated in task *C3.1* guided the design team in defining the key resources, activities, and partners needed to deliver the Smart PSS value proposition to the customer. Consequently, these prototypes are expected to be used to prompt discussions about the Smart PSS offering's feasibility. In this regard, new risks are likely to be identified by the design team, following the approach described in the previous methodological block (B).

We can illustrate the types of risks that may be identified in this task with the following examples:

(i)   Paiola and Gebauer (2020) documented that an industrial firm may decide to launch a Smart PSS offering that implies direct contact with the end customer. This situation may be perceived as a threat by the key distributors in the product-centric value network. These distributors could retaliate against the industrial firm, which would be detrimental to the current manufacturer's business model.

(ii)   We can also mention the risk that one of the key actors is not willing to establish a partnership as the Smart PSS offering does not fit their business model expectation.

All these potential situations are intended to be anticipated in this block. As explained in the previous block, a risk review is conducted at the end of the design iteration. Subsequently, the risk register is updated. The remaining methodological blocks of the sPS²Risk framework belong to the design loop called the 'iterative validation loop' (Figure 18) and are detailed in the following sections.

5.6 Methodological block D - Simulation and decision-making applied to the Smart PSS delivery scenarios

This methodological block is aimed to provide industrial decision-makers with in-depth insights into the economic performance assessment of the alternative Value Delivery Scenarios (VDS). These VDS representations, referenced as O5 in Figure 19, were created and stored on the 'value network' modelling view of the sPS²Modeller. This economic evaluation is carried out by employing the sPS²Simulator, mentioned in section 5.1.2. The sPS²Simulator uses a simulation approach to compute the expected profitability of each VDS resulting from the methodological block C's application. The simulation approach is a prototyping type that has been used in PSS evaluation to predict the PSS offering's performance (Phumbua and Tjahjono, 2012). The simulation approach often uses conceptual prototypes as inputs (Alix and Zacharewicz, 2012), as in the sPS²Risk framework.

Each VDS represents a configuration of actors and their associated roles under a specific economic model (i.e., product-, use-, result-oriented) to deliver a service package (i.e., PSS or Smart PSS service contract). The sPS²Simulator enables design team members to compare the expected profitability of each one of these VDS. This comparison is aimed to assist decision-makers in two aspects: (i) the selection of the value delivery scenario(s) to be tested with a group of real-world users, as is explained in the methodological block E, and (ii) the provision of an economic analysis that gives evidence of the Smart PSS VDS's financial viability. This evidence enables designers to justify investments in the technical development of the Smart PSS value proposition and the allocation of resources to develop a Minimum Viable Ecosystem (as addressed in the methodological block E).

Task D4.1: Formalization of the economic models to be simulated.

First, the design team must set the economic performance simulation's objectives (e.g., visualize the economic added value of Smart PSS offerings and select the most profitable value delivery scenarios to be tested). In order to meet these objectives and predict the KPI(s) modelled on the 'performance modelling' view of the sPS²Simulator, the insights obtained in the iterative design loop must be converted into an economic mathematical model. This mathematical model represents the profit equation for each value delivery actor considered as 'key' by the design team.

In order to formulate these profit equations, the conceptual models created during the methodological block C's application are used to define Cost Breakdown Structures (CBS) for each of these key-value delivery actors. Specifically, the conceptual models created on the modelling tool's views 'activity', 'organisation,' 'scenario,' and 'value network' are used to define these CBS. In parallel, the conceptual models created on the 'value network modelling view' are used to define the revenue streams for each key-value delivery actor in each VDS. These revenue streams may vary based on the associated economic model.
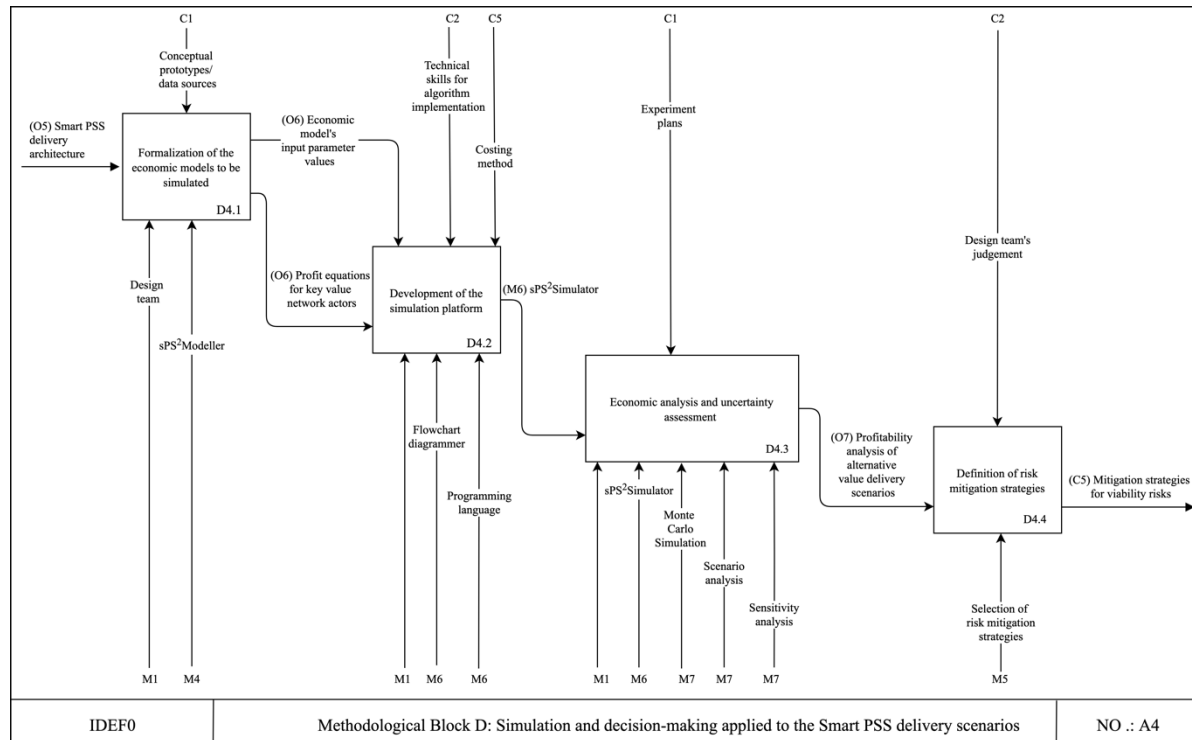
Figure 26. Internal breakdown for the methodological block D- Simulation and decision-making applied to Smart PSS delivery scenarios.

In this formalization, it is essential to consider the direct and indirect value captured through the digital service offering (Baines et al., 2020). Direct value capture refers to the payments made by the customer for the digital service (e.g., additional fixed monthly fees, output-based fees, while indirect value capture is linked to additional efficiencies (e.g., operating cost reduction in service provider's operations). These efficiencies are defined considering a PSS baseline scenario.

Once the costs and revenue streams involved in the whole Smart PSS's solution lifecycle, the profit equations for each key-value delivery actor are detailed. Then, the input parameters needed for these equations are listed. Based on this list, a plan to collect the information and data necessary to establish the value of these parameters is made accordingly. When the required information is gathered, input parameters associated with costs are calculated.

The approach presented in Farsi et al. (2020) is applied to calculate these costs and simplify the cost estimation process. In this costing approach, the lifecycle cost phases are identified, and then the cost activity values, and their expected annual frequency are assigned to these phases. Consideration must be given to new cost drivers such as connectivity hardware, data transmitting, storing, and analytics. Finally, these profit equations referenced as 'O6' in Figure 19 are integrated into a simulation platform as described in the following task.

Task D4.2: *Development of the simulation platform.*

The profit equations formalized in the previous task represent the financial flows among the value delivery actors during the whole Smart PSS' lifecycle (based on the conceptual models created on the 'value network modelling view' of the modelling toolkit). These equations were formulated for each alternative VDS (combining economic models and service packages). These profit equations representing the complete solution's lifecycle are structured as algorithms.

In order to guide the development of the simulation IT tool, these algorithms are graphically represented as flowcharts. This type of pseudocode facilitates communication between the design team and the IT developers. Building blocks can be developed from these pseudocodes and then adapted to each economic model. This technical development implies the coding process of the selected programming language. Besides, the simulation tool's dashboard must be designed during this task's application. This activity is carried out considering the data visualization needs of the design team.

This dashboard is integrated into the simulator and is aimed to show graphically and numerically the results associated with the simulated VDS. These results show the evolution of the key economic metrics over a simulation horizon, fixed by the user on the simulator. Thus, the impact of Smart PSS service packages on key economic metrics can be perceived. The simulator must enable practitioners to consider two options concerning the service packages: a combination of PSS and Smart PSS service contracts or a scenario where only one of the service packages is commercialized.

The simulator was conceived so that the user enters the values of the parameters (for example, the simulation period in months and the number of iterations) and then launches the simulation. Once the simulation run has finished, results are displayed monthly and year by year. These results are also displayed graphically through the dashboard abovementioned. Furthermore, these results are presented from the perspective of the key-value delivery actors.

In addition to this, the sPS^{2}Simulator generates a histogram that displays the structure of each actor's cumulative profit distribution. This distribution is traced out from the results of the simulation iterations. The user sets the number of iterations before launching the simulation. This functionality is enabled because the sPS^{2}Simulator integrates the randomness of a set of input parameters such as the market volume in each simulation iteration. Once the simulation tool deliverable is available (referenced as M6 in Figure 19), tests must be conducted to verify the reliability of the results provided by the simulation platform.

A second dashboard must be designed to enable the design team to compare the alternative VDS. As a reminder, a VDS combines an economic model (e.g., a use-oriented model such as leasing) with a service package (either PSS or Smart PSS). This second dashboard is aimed to provide decision-makers with insights into the potential viability of launching alternative Smart PSS and PSS offerings under

different input parameter configurations. The specifics of this second dashboard must be agreed upon with the design team based on the economic analysis' objectives defined in the previous task. The figures presented in this dashboard are extracted from the sPS^{2}Simulator. Further details about the development process and utilization of the sPS^{2}Simulator for a specific case study are presented in Chapter 6.

Task D4.3: Economic analysis and uncertainty assessment.

Once the simulation computer-based tool is ready for use, an experiment plan is created. This experiment plan is based on the comparative profitability analysis to be depicted in the second dashboard mentioned in the previous task. Here, the uncertainty assessment method 'Scenario analysis' (Refsgaard et al., 2007.p.1551) is applied to assess input parameter uncertainty. This uncertainty can be stochastic, epistemic, or both.

Given the uncertain nature of input parameter values, this experiment plan must deal with the variability of the input parameter values and represent the 'scenario analysis' assumptions (e.g., increasing market volume demand over time). Since simulation outputs are affected by this variability, the impact of the variation of input parameters on the key economic metrics and performance indicators (represented on the 'performance modelling view') must be tested. Accordingly, several input parameter configurations are defined and integrated into the experiment plan. These configurations should represent 'pessimist, realistic, and optimist' scenarios. According to expert opinion, the set of input parameters to be varied simultaneously in these configurations is established.

Once the experiment plan with the scenarios to be simulated is validated, simulation runs are executed following this plan. Each simulation run is replicated several times to estimate the uncertainty propagation on the previously defined key economic assessment outputs. The simulation results are compelled in the second dashboard that compares the alternative VDS. This dashboard recapitulates the leading economic performance indicators and metrics from a multi-actor perspective, based on the 'scenario analysis' experience plan. Next, practitioners use this dashboard to identify the input parameters that may have the most considerable impact on the key economic model outputs.

After defining this list of 'high-impact' parameters, a one-at-a-time (OAT) sensitivity analysis is carried out. A new experiment plan is needed at this stage. In this plan, a baseline input parameter configuration is selected, and then the value of the selected parameters is varied. The effect of this individual variation in the economic model output is plotted in a tornado diagram. The results represented in the second dashboard abovementioned, and the tornado diagrams are grouped under the 'O7' reference in Figure 19.

Task D4.4: Definition of risk mitigation strategies.

Based on the discussion of economic analysis results, the design team develops strategies to mitigate the viability risks. These strategies may involve redefining the value proposition, conducting additional interviews with key stakeholders, reformulating partnership contracts (e.g., transferring risk to other actors), redefining the assumptions based on more solid evidence, and carrying out a new set of simulation experiments. However, the Smart PSS development project will undoubtedly be discarded under these conditions: (i) the economic analysis shows unprofitability for one or several key stakeholders under several input parameter configurations, or (ii) the economic analysis shows that the offering is potentially unaffordable for the customer.

5.7 Methodological block E- Development and experimental prototyping of the Smart PSS solution

In case there is enough evidence that the Smart PSS offering is desirable by potential customers, feasible to implement, and financially viable for the actors concerned, the tasks of the methodological block E are applied (Figure 27).

This methodological block starts with a quick monitoring risk review, as explained in the methodological block C. The results of this review will assist the design team in deciding whether to continue with the Smart PSS solution development.

The service-based value proposition is more tangible than in the framework's beginning stage at this point in the design process. For this reason, at this point, the use of complementary and medium-resolution prototypes is suggested. Although the solution's technical development is outside the scope of this thesis, this methodological block was included due to the importance of the testing phase. This testing phase is aimed to obtain feedback from real-life experiments about aspects such as the Smart PSS offering's scalability and user experience. This feedback can be used to refine any of the BMI dimensions before decision-makers eventually decide to launch the Smart PSS offering in the market.

Task E5.1: Development of the Minimum Viable Product (MVP).

This experimental prototype involves the concurrent development of (i) the product's smartness (e.g., sensor's integration into the product), (ii) digital service (algorithm development, user interface, implementation of data collection, storing, and analytics), (iii) digital platform (web interface), (iv) a Minimum Viable Ecosystem (MVE), and (v) the basic services' blueprinting. Widespread agile development methods such as Scrum are suitable for creating a Minimum Viable Product (MVP). This MVP (Figure 28), referenced as 'O8' in Figure 19, encompasses the digital service(s) and its interaction with the smart product and the digital platform in an MVE. This MVE involves the collaborative work among business partners (value network actors) to deliver the Smart PSS solution's key functionalities.

However, it should be noted that the Smart PSS solution's technical aspects development goes beyond the scope of this design framework.
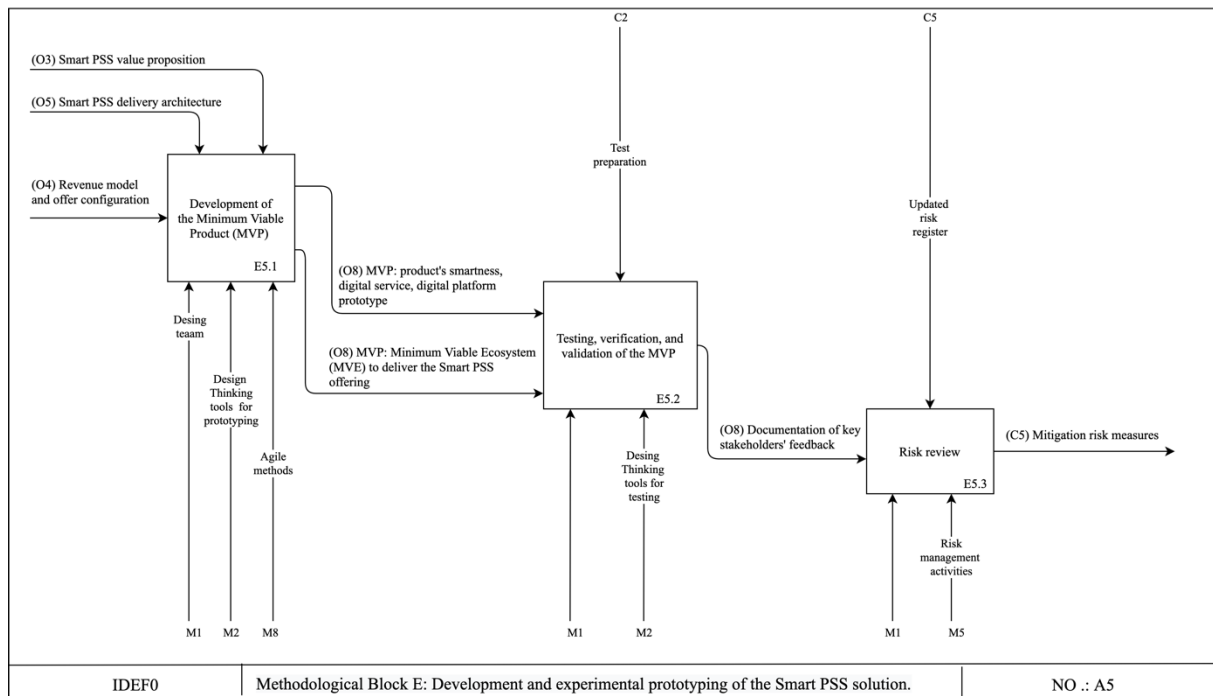
Figure 27. Internal breakdown for the methodological block E- Development and experimental prototyping of the Smart PSS solution.
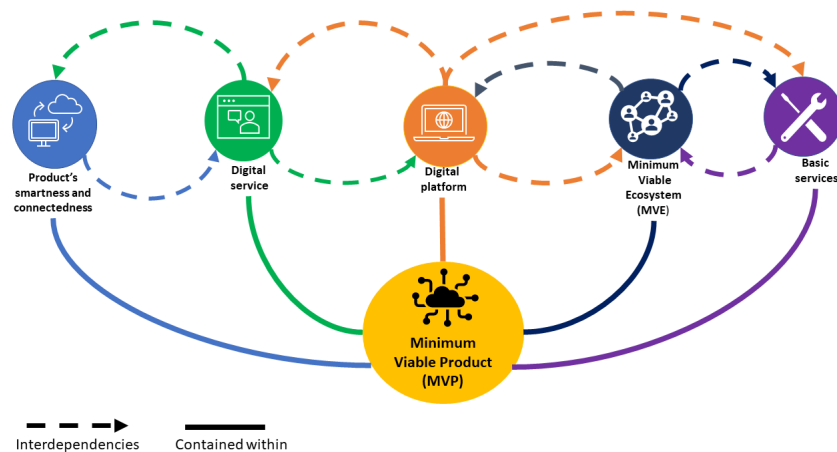
Figure 28. Smart PSS Minimum Viable Product.

Task E5.2: Testing, verification, and validation of the MVP.

Once an MVE has been established, the MVP is tested with a sample of users. This testing stage is aimed to document valuable feedback from customers in a real context about the MVP. This feedback allows the cross-functional to infer whether the solution creates value for the customer and other stakeholders. This value can be classified into various dimensions like environmental and social impacts and customer value. However, these specific value dimensions are beyond the next methodological block's scope.

This testing stage is decisive as designers determine if the service-based proposition resulting from methodological block B targeted the most critical customer jobs, gains, and pains. Besides, they will obtain practical evidence about the win-win conditions for the service delivery actors. Therefore, based on the inferences from the testing findings, the cross-functional team may decide to refine either the value proposition or the value network, or both. Thus, testing's results may guide designers to enhance the solution's value-in-use experience. This collected feedback may also be used to improve the processes involved in service delivery.

Task E5.3: Risk review.

A set of risks that threaten the solution's feasibility and viability may also be identified from this testing step. These risks are likely related to the solution's smartness and usability. Notably, designers may detect issues resulting from the integration of hardware and software components, the deployment of these components in the service units, and data handling aspects such as IT security. Moreover, this MVP experimental testing step conduces to a more comprehensive cost structure. Risks that concern the Smart PSS offering's viability may be detected from this summary of operating costs (e.g., high data analytic costs, volatile operating costs). These detected risks provide additional insights into innovation-related risks that could have been identified in the previous methodological blocks.

Conclusions

This chapter presented a value-driven Smart PSS design framework called sPS²Risk, composed of five methodological blocks. The tasks and methods incorporated in these methodological blocks were described to guide practitioners in the framework's implementation. Two significant needs were identified from the interactions with elm.leblanc's practitioners. These needs also were identified as gaps in the Smart PSS literature. These industrial needs and gaps, described below, motivated this design framework's development:

(i) The necessity to integrate the Business Model Innovation dimensions proposed by Gassman et al. (2014) into an easy-to-implement design framework. These dimensions are the value proposition design, the value delivery configuration, and the definition of the profit mechanism.

(ii) The need to anticipate the highest impact innovation risks that threaten the industrial firm's financial health.

These gaps were addressed in the proposal by including five methodological blocks in the design framework. The first methodological block of this proposal, *'elicitation of stakeholders' value expectations*,' provides guidelines to identify critical stakeholders and collect their needs or win conditions in the value network. The methodological block B, *'prototype of general value concept*,' advocates a series of tasks and methods to devise and sketch the service-based value proposition. The following methodological block, *'specification of the detailed value concept*,' describes the steps to outline the alternative value networks to deliver the service-based value proposition. The

methodological block E, *simulation, and decision-making applied to the Smart PSS delivery scenarios* stipulates the tasks to estimate the alternative value network scenarios' profitability from a multi-actor perspective. Lastly, the methodological block E, *'development and experimental prototyping of the Smart PSS solution*,' focuses on the prototype elaboration and testing of the solution embedded in the service-based value proposition.

As described in section 5.1.1, concerning the methodological foundations of the proposal, the Incremental Commitment Spiral Model's (ICSM) proposed by Boehm et al. (2014) inspired the structuration of the sPS²Risk Framework. In this regard, the ICSM's fourth principle was adopted in this design framework by integrating risk management activities into most of the methodological blocks of the proposal. This integration aims to provide evidence- and risk-based decisions during the Smart PSS design and development. Furthermore, ICSM's stakeholder value-based guidance principle inspired the formulation of the methodological blocks A and B. Lastly, ICSM's principles concerning incremental commitment and accountability and concurrent multidisciplinary engineering were considered in the tasks of methodological blocks C and E.

The following chapter details the utilization and development of the tools built to support the application of the design framework presented in this chapter (the sPS²Modeller and sPS²Simulator). Integrating both computer-aided tools into one single tool, which could be reused by elm.leblanc to design offerings aimed at other customer segments, remains a perspective.

Chapter 6. A Modelling and Simulation Toolset to Support the Implementation of the sPS²Risk Framework

Introduction

The preceding chapter presented the core of this thesis, a value-driven Smart PSS design framework. As this proposal aims to be industrially applicable, its usability in real contexts played a significant role during the design framework's conceptualization. Consequently, the tools necessary to support the implementation of the sPS²Risk Framework's methodological blocks were defined and integrated into the proposal (Figure 29). In addition to including well-known design tools, two computer-aided tools were built to facilitate the design framework application within the case study industrial firm. The development of these customized IT tools for the Smart PSS design context in the residential heating appliance industry was aimed to meet the sPS²Risk framework's iterative prototyping principle. Hence, the developed computer-based tools aim to provide two complementary types of prototypes during the early Smart PSS design phase: the conceptual models (section 6.1) used as an input to perform the economic performance simulation (section 6.2).

In Chapter 2, Smart PSS was defined as a complex system composed of products, services (basic and digital), and value networks. Then, in chapter 3, the need for design team members to visualize the various components of the system during the design phase to address this complexity was highlighted. Based on this literature review, conceptual modelling was singled out as a suitable prototyping approach to establish a common understanding of the service-based offering design and improve the overall

process of value system design. Subsequently, a conceptual modelling toolkit was built to support the proposal's application in a real setting. This IT tool called sPS²Modeller consists of a modelling software program that provides a set of graphical representations of the Smart PSS system components corresponding to the framework's requirements.

In chapter 4, the simulation approach was acknowledged as appropriate to estimate the service-based offering's profitability from a multi-actor perspective. Therefore, to evaluate the viability of the alternative value network configurations, a performance economic assessment simulator was developed to support the tasks included in the methodological block D, called '*simulation and decision-making applied to the Smart PSS delivery scenarios*' This computer-based tool called sPS²Simulator comprises a stochastic simulator that estimates key economic performance indicators of the actors involved in the Smart PSS delivery network(s).

The main objective of integrating modelling and simulation tools into the proposed framework is to aid in the decision-making process related to the focal firm's strategic, tactical, and operational planning (e.g., the choice of implementing a specific service-based economic model over other options, value proposition definition). Even though employing modelling and simulation approaches is a widespread approach in several engineering domains, their combined use in PSS and Smart PSS remains limited. Examples of design frameworks using both modelling and simulation approaches in PSS can be found in Pezzotta et al. (2015) and Andriankaja et al. (2018). The following sections explain the employment of this modelling and simulation approach in the proposal using the customized IT tools.

The remainder of this chapter is structured as follows. Section 6.1 elaborates on the modelling toolkit's development process, functionalities, and employment in the proposed framework. The same aspects concerning the economic performance simulation tool are detailed in section 6.2.
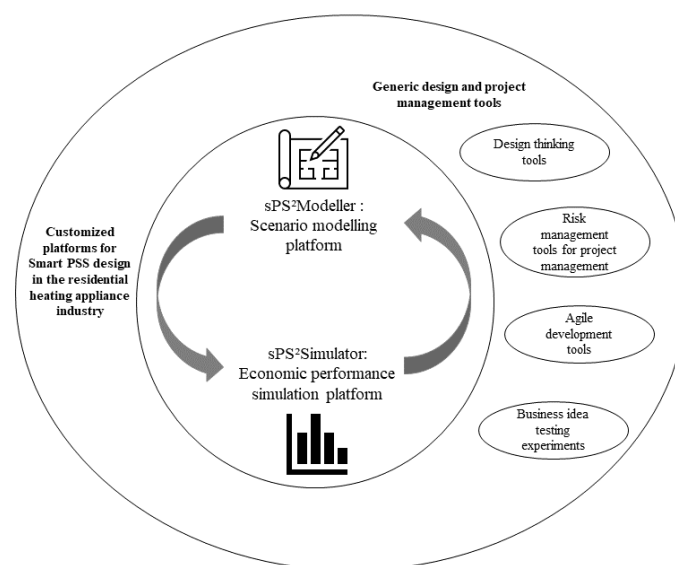
Figure 29. The overall toolset proposed to apply the sPS²Risk framework.

6.1 Conceptual modelling tool

The requirements to make operational the proposed Smart PSS design framework were identified to define the toolset environment shown in Figure 29. These requirements were derived from the elements retained from the review literature presented in Chapter 3 and workshops with practitioners of elm.leblanc. Considering the Business Model Innovation (BMI) dimensions (Gassmann et al., 2014), these requirements are synthesised in Table 8. These dimensions are not addressed holistically in the existing Smart PSS design frameworks.

Table 8. Conceptual prototyping requirements derived from the literature and interactions with practitioners.

BMI dimension (Gassmann et al., 2014)	Conceptual prototyping requirements
The customer	(i) Visualize the customer segment targeted by the servitization efforts. (ii) Describe the stakeholders' needs collected from the need-finding process. (iii) Characterize the demand associated with the target customer segment. (iv) Display the Design Thinking tools employed in the sPS^{2}Risk framework.
The value proposition	(i) Visualize the physical and intangible elements of the Smart PSS value proposition (products, basic services, and digital services) included in the whole Smart PSS offering's life cycle. (ii) Link the Smart PSS value proposition elements with stakeholders' needs. (iii) Represent the value offering (Sjödin et al., 2020).
The value network	(i) Visualize the actors involved in service delivery, their roles, the value transactions among the actors to deliver the Smart PSS value proposition, and the performance indicators associated with the Smart PSS delivery. (ii) Enable the representation of alternative service delivery networks.
The profit mechanism	(i) Facilitate the collection of the information needed to formulate the profit equations (cost structures and revenue streams).

These requirements were considered in this modelling tool's development to support the implementation of the sPS^{2}Risk framework in elm.leblanc's design activities. The remainder of this section describes the specific requirements addressed by the conceptual modelling tool in each methodological block. In the 'strategic contextualization' step preceding the sPS^{2}Risk framework's application, the business ecosystem output was decided to be modelled on the modelling toolkit. The inclusion of this conceptual model is aimed to facilitate the elaboration of this model compared to paper-based approaches.

As the methodological block A is grounded on well-established methods and tools such as Design Thinking (Lewrick et al., 2020) and Value Proposition Canvas (Osterwalder et al., 2014), it was decided that the IT modelling tool would allow storing the methodological block A's outputs. Therefore, a key functionality identified for this first computer-based tool is to serve as a project design repository. Additional pieces of design information issued from applying the proposed toolset in the remaining

methodological blocks are summarized in Table 9. These documents are also aimed to be stored in the IT modelling tool.

Table 9. Pieces of information that can be stored in the modelling tool.

sPS²Risk framework's methodological block	Generic design and project management tools	Pieces of data to be stored
A	Design thinking tools	Customer journey, 'how might we' questions
B, C, D, E	Risk management tools for project management, business idea testing experiments	Risk register, description of control measure risks, outputs of risk control measures.
E	Agile development methods	Scrum artefacts: User stories, product backlog, sprint backlog, increments, definition of done, etc.

The more substantial need for qualitative modelling emerges in the methodological blocks B and C. Following the framework's loops, for the methodological block B, a key IT tool functionality identified was the generation of sketches covering the value proposition elements (products, services, and customer benefits). For the methodological block C, the required sketches must depict the value network elements that deliver the value proposition to the customer. Based on these prototyping needs for the iterative design loop of the sPS²Risk framework (Figure 19), conceptual modelling was selected as the prototyping technique to generate these low-resolution sketches. Accordingly, a tailored computer-based tool called sPS²Modeller was built to address this prototyping need. This IT tool is aimed to be utilized during the application of the proposed framework's methodological blocks B and C.

The sketches created by sPS²Modeller consist in conceptual models employing customized graphical notations instead of standardised notations such as BPMN (Business process model and notation). A conceptual model is defined as a simplification of the system of interest (Banks et al. 2009), in this case, the Smart PSS offering. This simplification only includes the aspects that affect the problem of the study (value proposition, service delivery network, value capture mechanisms).

In addition to enabling the visualisation of an idea, these models serve as a data structure to capture essential information from the design process. Thus, in parallel with the graphical visualization, a knowledge base on design information is also built as the modeller is used throughout the sPS²Risk framework. Therefore, these conceptual models allow both structured and shared access to the knowledge base for all project stakeholders. This knowledge base is aimed to collect the key information necessary to formulate the Smart PSS economic models. These economic models are then simulated in the sPS²Simulator as described in section 6.2.2.

The advantages of using this approach in the Smart PSS design context can be summarized as follows:

(i) The Smart PSS system can be abstracted, just as CAD (computer-aided design) models allow it in product development. This abstraction is aimed to be a decision-making supporting tool concerning the PSS tactics defined by Reim et al. (2015). These tactics are related to contract design, marketing, network relationships, product and service design, and sustainability.

(ii) The graphical representations created by this IT tool ease the communication and shared understanding of the details of what is being designed among the transdisciplinary team of internal actors and external stakeholders.

(iii) Multiple design alternatives that include the various potential models to deliver the Smart PSS offering can be prototyped following an iterative agile approach. These conceptual models allow for the capitalization on the key configuration information of the economic models. Therefore, these models facilitate the development of the financial performance simulator employed in the methodological block D.

(iv) A knowledge base can be constructed throughout the implementation of the sPS^2Risk framework. The data stored in this base is essential to define the value delivery networks to be simulated and, consequently, build the $sPS^2Simulator$.

6.1.1 Positioning

Valencia Cardona et al. (2014) pointed out that selecting tools in the Smart PSS design process remained challenging, mainly due to this design field's recentness. These academics reported that conventional design tools such as prototypes, drawings, and storyboards have been employed in Smart PSS design by the practitioners they interviewed. According to their findings, these conventional tools seem effective in Smart PSS design. However, they expressed that Smart PSS design may entail the development of tailored tools to cope with the specific challenges of this design field. Examples of these challenges are value proposition definition, stakeholder management, and clear communication of design goals.

In PSS design literature, Phumbua and Tjahjono (2012) highlighted that an inappropriate design tool's utilization may lead designers to make poor decisions. This situation could harm the industrial firm's economic performance. These same scholars documented that most tools employed in PSS design were commercial modelling software programs such as Business Process Modelling Notation (BPMN) modellers. Accordingly, these scholars suggested that using a PSS-specific modelling tool is a well-suited means to deal with the PSS design complexities.

Few PSS and Smart PSS modelling computerized tools can be found in the literature (Table 10). Among them, one can highlight Service Explorer (Hara et al., 2009), ComVantange (Buchman, 2016), and PS3M (Boucher et al., 2018). Other PSS-specific visualization tools, such as PSS board (Lim et al., 2012) and Product-service blueprint (Geum and Park, 2011), were reported as conceptual propositions without being implemented in a software system. This situation exemplifies the gap between the plethora

of conceptual PSS-oriented design frameworks and ready-for-use PSS-specific design supporting tools as corroborated by Valencia Cardona et al. (2014). Their study interviewed professionals who took part in Smart PSS design projects, and no evidence of the utilization of tools associated with PSS design was found.

Given this situation, a modelling toolkit called sPS²Modeller was developed to bridge the gap between the framework conceptualization and its applicability to the case study manufacturer. The models displayed and stored on sPS²Modeller are aimed to provide the cross-functional design team with insights into the Smart PSS system. These insights may be used as reference points to aid decision-making in three aspects:

(i)   At a strategical level, concerning the economic model that the Smart PSS offering could be based on.

(ii) At an operational level, regarding the tactical sets identified by Reim et al. (2015) that concern the value proposition design (contract design, product, and service design) and the value network configuration (marketing, network relationships).

(iii) Exploring the Smart PSS offering's desirability, feasibility, and viability during the early design phase, an angle that remains unexplored in Smart PSS literature.

A significant issue associated with the design process of service-oriented offerings was aimed to be tackled by sPS²Modeller's development. This issue concerns the intellectual efforts described by Valencia Cardona et al. (2014), in which the design team often must shift from a system-level mindset (considering the Smart PSS offering as a whole) to the system details. To tackle this challenge, sPS²Modeller was structured into ten modelling views described in section 6.1.2. Each of these views represents Smart PSS offering components and their associated subcomponents. Additionally, the conceptual models created by sPS²Modeller employ graphical notations to exploit the benefits of the visual thinking design technique.

The benefits of this technique's application are twofold. Firstly, a modelling language should propose a graphical representation easily understandable by distinct internal stakeholders of the industrial firm and external stakeholders. Hence, the modelling language facilitates the multiple interactions among stakeholders during the iterative design loops. Secondly, more solid insights resulting from the validation of the conceptual prototypes within the design team are expected. This is explained by the perception that people react more actively to images than words (Osterwalder et al., 2010). In that regard, higher quality insights derived from the validation tasks may be obtained if the conceptual prototypes use pictograms rather than standard notations. In the latter case, practitioners may not straightforwardly differentiate the various objects modelled in the conceptual prototype.

Consider the prototypes of the alternative value delivery networks. Here, the visual representation of different categories of stakeholders involved (e.g., manufacturers, basic service providers, digital service

providers) may trigger more explicit discussions about the innovation risks associated with the inclusion of these actors in the Smart PSS delivery network. For example, what if questions such as "what if we do not find enough installers to meet the demand?" can be formulated from the collaborative validation of these conceptual prototypes. Once potential risks are collaboratively identified, the design team estimates the occurrence probability of that risk and the possible mitigation strategies.

Concerning the employment of prototypes for innovation risk identification, Lewrick et al. (2018) affirm that "*the test results of the prototype serve the project team as a basis for decision-making in order to make the right, balanced decisions in terms of human desirability, economic feasibility, and technical implementability.*" In other words, testing and validating the conceptual models with internal stakeholders can effectively provide the basis for risk innovation identification. Thus, the conceptual prototypes related to the value proposition elements and value network may boost the collaborative innovation risk identification activity.

6.1.2 Conceptual modelling tool development

Following the identification of existing modelling languages presented in Table 10, a starting point to build sPS²Modeller was selected: the modelling language and tool PS3M, introduced in Boucher et al. (2018). This choice was made because this tool generates conceptual models that meet the prototyping requirements of the sPS²Risk framework's iterative design loop (Figure 18). Moreover, this tool is implemented in a user-friendly platform called ADOxx (https://www.adoxx.org/live/home). This ergonomic characteristic favours the easy deployment of the tool in the activities of the case study manufacturer.

Given the above arguments, the modelling language building method presented in Medini and Boucher (2019) was used to build a modelling tool tailored to Smart PSS design (Figure 30). PS3M was developed in a PSS engineering context. Thus, this modelling toolkit was not aimed at covering all the requirements identified for Smart PSS design. However, PS3M constitutes a good starting point for developing a language extension.

To begin with the development of the computer-based modelling tool, the PS3M metamodel presented in Idrissi et al. (2017) was modelled on the UML modelling platform Eclipse. Then, this metamodel was enriched by extracting additional concepts and associations from Smart PSS literature and the description of a heating appliance Smart PSS offering existent in the French market. Literature reviews on Smart PSS design, digital servitization, and value architecture in servitization (Chowdhury et al., 2018; Maleki et al., 2018; Garcia Martin et al., 2019; Zheng et al., 2019; Cong et al., 2020; Paschou et al., 2020) were used to confront the key Smart PSS concepts identified with the input metamodel.
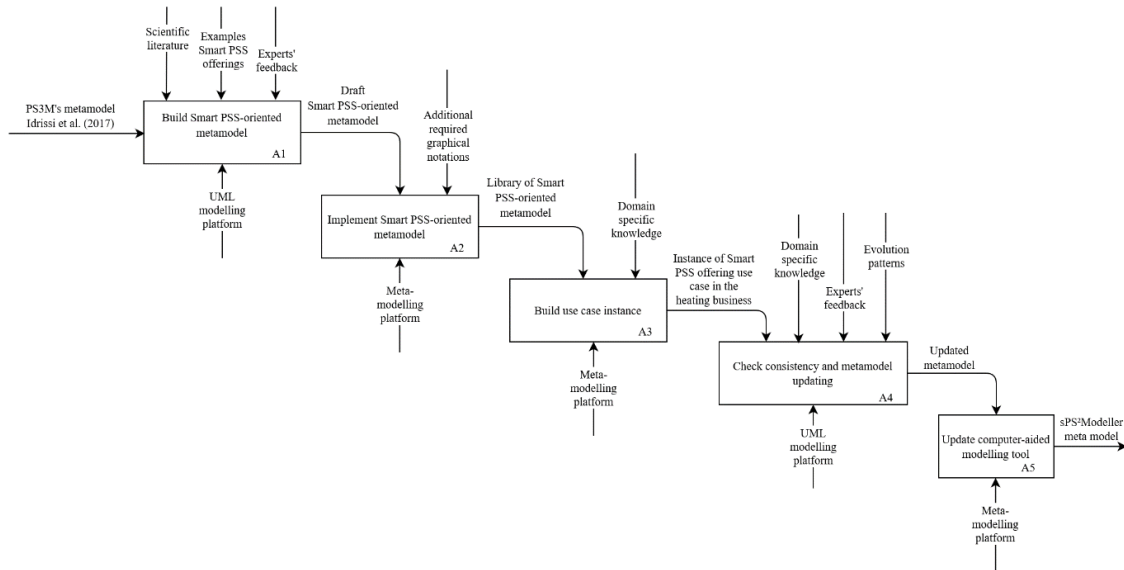
Figure 30. Development of the IT modelling tool. Adapted from Medini and Boucher (2018).

The subsequent modifications made to the metamodel presented in Medini and Boucher (2019) can be summarized as follows:

(i)   creation of new modelling views

(ii)   adaptation of PS3M's modelling views to the sPS^{2}Risk framework's characteristics,

(iii)   the upgrade of the graphical notations used in the conceptual models aimed to enhance the IT tool's usability.

These modifications are further detailed in the following subsections.

Table 10. Overview of PSS and Smart PSS-specific visualization tools.

Design field	Modelling Tool	Associated design framework	Modelling Views to support value proposition design	Modelling views to support value network configuration and stakeholder management	Application case study
PSS	Service explorer: Hara et al. (2009)	Modelling method for service based on service blueprinting extension.	Not explicitly mentioned.	It contains two modelling views. (i) *Activity blueprint:* This view specifies the service delivery process and the interactions between the customer and the provider. These interactions occur between the customer and the tangible PSS part and between the human resources and the equipment and facilities involved in PSS delivery. (ii) *Behaviour blueprint:* it details the behaviours of the objects involved in service delivery.	B2B: Elevator operating service.
PSS	PSS DesignScape Tool: Kim et al. (2011)	Product-Service Systems Design with Functions and Activities.	*(i) Life-cycle modelling:* life-cycle steps, stakeholders, and requirements are detailed. (ii) *PSS representation tool:* it represents the services and products that compose the PSS offering.	(i) *PSS scenario generation tool:* It displays activities and stakeholders involved in PSS delivery, material, energy, and information. Material inputs and output flows are defined. (ii) *Activity modelling tool:* Activities are described in more detail. Seven elements are included: activity, actor, object, tool, event, context, and environment. (iii) *PSS function modelling tool:* Critical functions are defined; service provider and receiver are identified. (iv) *PSS modified service blueprint tool:* Alternative PSS concepts can be configured and compared by mapping and locating different activities performed by various stakeholders.	B2C: Clothing donation.
PSS	Service explorer: Pezzotta et al. (2015)	Service CAD methodology	*View model:* it defines how customer value, represented by Receiver State Parameters, and actual entities (human resources, supporting products) are related.	(i) *Flow model:* It displays the relationships among a value chain's various stakeholders. (ii) *Scope model:* It details the activities taking place between a receiver and a service provider. (iii) *Extended service blueprint (activity and behaviour blueprinting editor):* The description of the relationships between functions and entities is represented in a service blueprint.	B2B: Repair workshop of a truck company.
Smart PSS	Comvatage: Buchman (2016)	ComVantage	*Motivators:* This facet describes the object of the enterprise activity. In other words, value models that incorporate both product features and associated services.	*Participants:* This facet includes resources that may be linked to service delivery: liable entities (i.e., business entities), assets (i.e., mobile apps, data sources), and capabilities (i.e., the business value provided by partners).	B2B: Mobile maintenance.

PSS	PS3M: Boucher et al. (2018)	Integrated product-service systems based on the extended functional analysis approach	- Requirements view - Product view - Service view - Demand view - Offer view	- Activity view - Organisation view - Performance view - Scenario view	B2B: Industrial cleaning.
PSS	SEEM: Pirola et al. (2022)	SErvice Engineering Methodology (SEEM)	- *Customer perspective:* It models the main characteristics of the customers by considering the customer needs, activities, values, and issues. - *Solution perspective:* It represents the combination of products and services by modelling the tangible and intangible parts of the solution/	- *Process perspective:* It models the service delivery process of the PSS solution by considering the company and customer activities, the resources needed, and the company performance.	B2B: Automation systems for residential use.

6.1.2.1. *Creation of new modelling views:* Two new modelling views and their corresponding classes were added to PS3M: the 'ecosystem' and 'value network' modelling views. These modelling views were incorporated to respectively support the operationalisation of the 'Strategic contextualization' step that precedes the sPS^{2}Risk framework's implementation and the methodological block C 'Specification of the detailed value concept.' The 'ecosystem modelling view' was incorporated to facilitate the stakeholder mapping task included in the 'Strategic contextualization' (Section 5.2). This task aims to visualize the stakeholders involved in the manufacturer's traditional product-based value chain.

The 'value network' modelling was developed to create the conceptual prototypes resulting from the application of the task 'C3.1', called 'Design of the value network' (Section 5.5). This modelling view was created to depict the potential alternative value delivery networks. Accordingly, this view enables practitioners to configure multiple value network prototypes. These prototypes combine different actors and service packages to deliver the Smart PSS value proposition under a specific service-oriented economic model (i.e., product-, use-, or result-oriented). In these models, the actors, the value objects exchanged, the value transactions, and the data/information flows are represented.

- 6.1.2.2 *Adaptation of PS3M's modelling views to the sPS^{2}Risk framework's characteristics*: An initial review was conducted to determine the PS3M's modelling views that could support the sPS^{2}Risk framework's implementation. Then, each modelling view was examined to determine the modifications needed. These modifications were made based on the literature review on Smart PSS findings and the representation of a Smart PSS offering in the heating business. The made changes concerned the following aspects:

- The class 'service' was subdivided into two new classes: 'basic services' and 'digital services.' These classes are employed in three modelling views: 'service,' 'offer,' and 'activity.'. By basic services, we mean the base and intermediate services defined by Baines et al. (2017), such as troubleshooting and product installation, where there is no involvement of digital technologies.

- The 'connectivity gateway' class was added in the 'product modelling view' since connectivity components (e.g., smart thermostats) must be well defined in the design phase (Zheng et al. 2019).

- -The 'stakeholder' class was created considering that a Smart PSS value proposition simultaneously creates value for diverse stakeholders. These stakeholders influence the success of the Smart PSS offering commercialization and must be considered in the design phase. This class was added to the 'service modelling view.'

- The class 'risk' was integrated since a key characteristic of service-oriented offerings is transferring risks from the customer to the service provider and other value network actors (See Figure 5). Then, visualizing what operational risks are assumed by the actors is meaningful in the design process. These actors also provide resources to deliver the offering. This class was integrated into the 'organisation' modelling view.

- The subclass 'intellectual resources' was integrated into the class 'resources.' This subclass represents resources such as know-how, patents, and customer databases, which have a pivotal role in Smart PSS delivery. The resource class is depicted in the models created on the 'organisation view.'

The metamodel shown in Figure 31 is an extension of the PS3M metamodel presented in Medini and Boucher (2019). This metamodel is the backbone of the resulting modelling toolkit, the sPS^{2}Modeller. Two validation stages were carried out in this development process. The first validation stage consisted of a conceptual validation of the final metamodel presented in Figure 31. The second validation stage involved elm.leblanc's practitioners and was aimed at testing the usability of the sPS^{2}Modeller. This technical validation is described in section 6.1.5.

For the first validation stage, the metamodel associated with sPS^{2}Modeller was reviewed with scholars from the servitization field. It is important to note that maintaining the metamodel's simplicity was the leading objective during this extension process. This simplicity takes into consideration the practitioners' preference for uncomplicated and business-like tools. This stage aimed to validate the collection of the main elements related to the Smart PSS offering design process in the metamodel. These key elements were considered from the business value perspective. Once academics validated the final metamodel, a platform was used to implement the metamodel and develop a computer-based modelling tool called sPS^{2}Modeller.
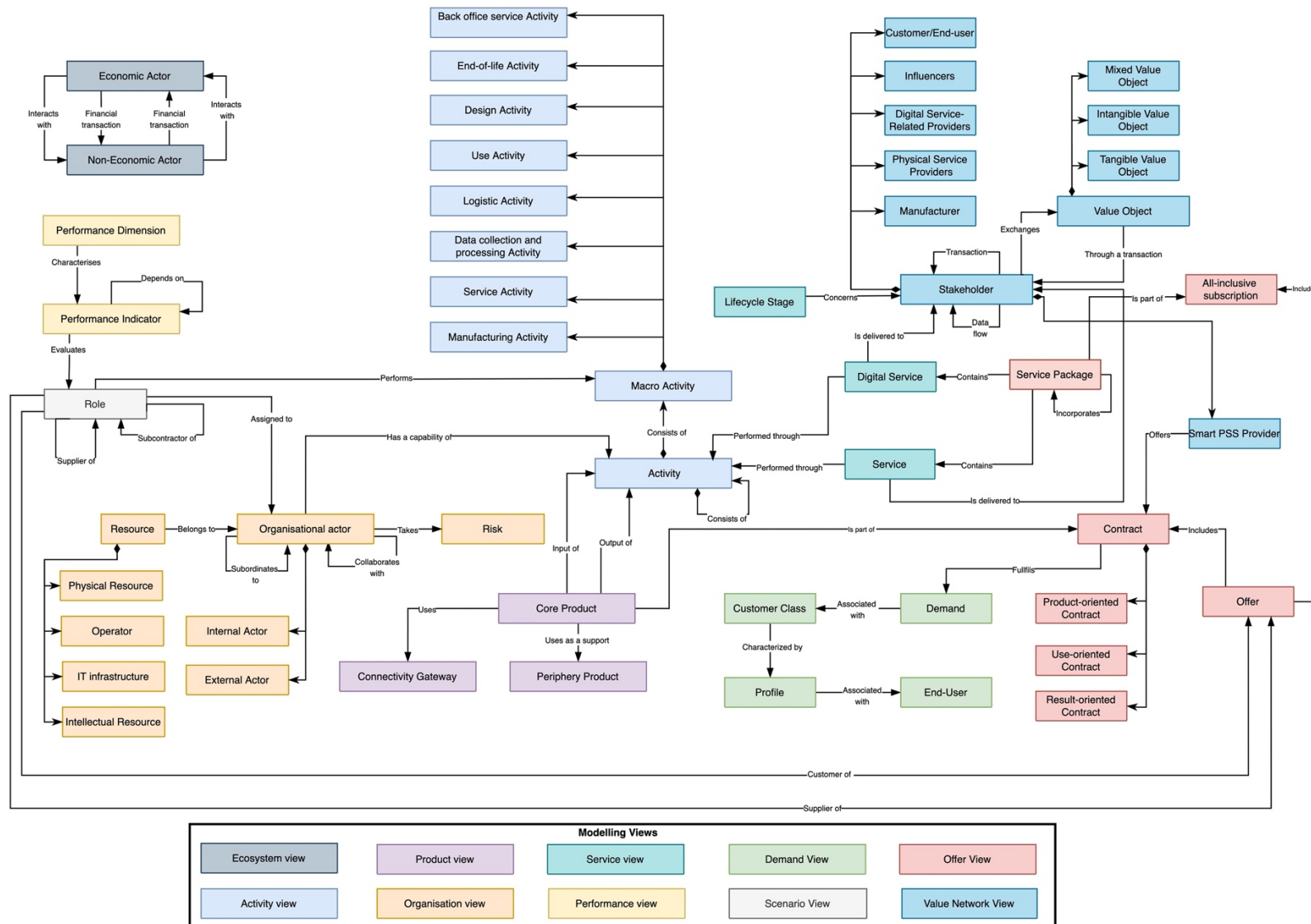
Figure 31. Resulting Metamodel associated with sPS²Modeller.

6.1.2.3 *Upgrade of the graphical notations used in the conceptual models:* The graphical notations of the PS3M modelling tool were upgraded. This upgrade was carried out to create conceptual prototypes that were easy to understand by the targeted audience (elm.leblanc's professionals). New graphical notations were included in sPS^{2}Modeller to represent the classes reutilized from PS3M (Figure 32). These pictograms are aimed to make the generated conceptual prototypes more intuitive. In addition, graphical notations were created for the new classes included in the metamodel associated with sPS²Modeller (Figure 31).This sPS^{2}Modeller modelling toolkit is presented in the following section.

Examples of upgraded modelling objects from PS3M included in the sPS²Modeller :

Examples of new modelling objects included in the sPS²Modeller:

Figure 32. Example of upgraded graphical notations.

6.1.3 The final artifact: the sPS^{2}Modeller

The sPS²Risk metamodel presented in Figure 31 was implemented on the ADOxx platform. The final artifact obtained from this implementation is an ADOxx library. This library consists in a software program that we call in this work 'the modelling toolkit' (Figure 33). This toolkit has ten modelling views, which is as many as the backbone metamodel of this modelling tool. They are named: 'ecosystem', 'product, 'service', 'demand', 'offer', 'activity', 'organisation', 'performance', 'scenario', and 'value network'.
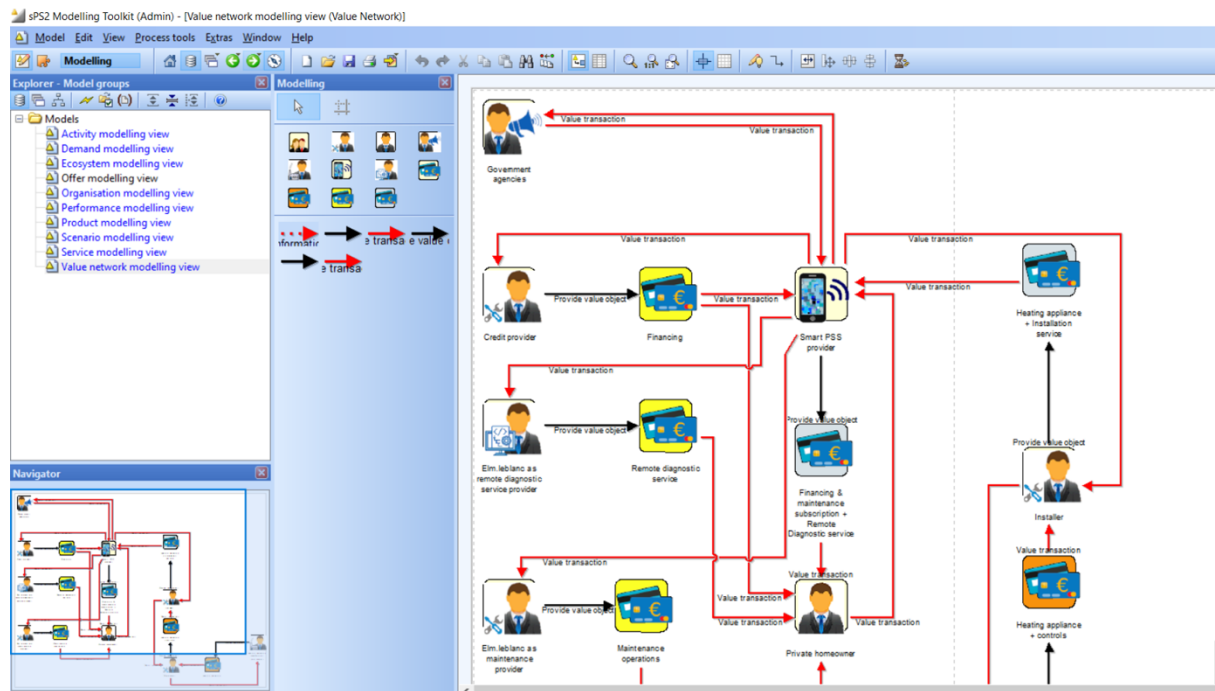
Figure 33. Snapshot of the user interface of sPS²Modeller.

Each of these 'modelling views' corresponds to a specific type of conceptual model. These modelling views cover the conceptual prototyping needs and knowledge management of the sPS²Risk framework. In turn, each conceptual model contains a particular set of modelling objects, graphical notations, and associated information stored in the objects represented. These conceptual models enhance the clear communication of Smart PSS design goals through the visual representations generated on the modelling views.

As previously mentioned, the sPS²Modeller offers the possibility to create ten different conceptual models. The 'ecosystem modelling view' is employed in the 'Strategic contextualization stage,' and the remaining nine modelling views are used throughout the application of the sPS²Risk framework. These remaining views can be grouped into two categories: 'structural' and 'behavioural' perspectives of the Smart PSS offering.

The 'structural' perspective gathers the views that represent the Smart PSS architecture. At an operational level, these structural modelling views are aimed at assisting in the decision-making process related to product and service design (e.g., the choice of digital service functionalities, product connectivity with sensors and periphery products), network design (e.g., partner selection, type of relationships with the customer), marketing operations (e.g., the definition of customer channels), and contract formalization (e.g., risk-sharing among value network actors, description of actors' responsibilities) (Reim et al., 2015). This structural category comprises four modelling views, each one briefly described in Table 11.

The 'behavioural' perspective aims to cluster the models that represent the dynamic features of the Smart PSS offering. These features are related to the alternative value networks that can deliver the offering. The models gathered in this category are aimed to assist the decision-making process at a strategic and operational level. Concerning the alternative value networks, these models allow for collecting information and obtaining insights into the alternative economic models through which the Smart PSS offering can be sold.

Regarding the decision-making process, the conceptual models assist decision-makers by facilitating the identification of clues about various tactical sets. Among these tactical sets, we find those that concern network design (e.g., planning information sharing and coordination activities scenarios), contracts (e.g., terms of the agreement, clarification of actors' liabilities), sustainability (e.g., definition of value capture mechanisms, the establishment of economic and environmental performance indicators). This behavioural category comprises five modelling views, and each view is briefly described in Table 12.

The proposed framework presented in Chapter 5 generates an important volume of design knowledge (Table 9). This knowledge must be shared within the design team and with external stakeholders. Hence, sPS²Modeller was conceived to store the various documents issued during the design loops. For instance, documents such as the customer journey diagram(s) elaborated in the methodological block A, the 'risk register' updated throughout the framework's application, and the user stories that lead the development of the MVP in methodological block D can be stored on the modelling tool. The model generated on sPS²Modeller can be stored in ADL format and exported to formats such as JPG and PNG for their documentation. Thus, sPS²Modeller serves as a project repository where critical design information can be accessible to all the value co-creation process actors.

Table 11. Overview of structural modelling views.

Modelling view	Description of the model generated
Product	It represents the overall structure of the core products integrated into the Smart PSS offering, the periphery products that support the solution delivery, and the connectivity devices.
Service	It displays the catalogue of digital and non-digital services that may be delivered throughout the entire heating appliance Smart PSS life-cycle steps: configuration, installation, maintenance, upgrade, and uninstallation/final disposal.
Activity	It represents the processes and activities required to deliver the Smart PSS offering. These activities can be differentiated by scope: logistic, design, front office, back office, and use activities.
Organization	It displays the potential value network actors and their capabilities to take charge of the activities required for Smart PSS delivery and the operational risks assumed by these actors that the customer traditionally bears. The key resources are categorized into human, physical, intellectual, and software/IT infrastructure.

Table 12. Overview of behavioural modelling views.

Modelling view	Description of the model generated
Demand	It structures the potential market with a set of customer categories (characterized by a commercial and a usage profile) associated with quantitative information on the demand.
Offer	It represents the combination of products and services integrated within a specific value offer and provides an overview of the contracts between the Smart PSS provider and customers.
Performance	It defines the performance indicators on which the Smart PSS offering will be assessed.
Scenario	It represents the alternative Smart PSS delivery networks, displaying the actors' roles and their expectations from the Smart PSS offering commercialization.
Value Network	It displays the alternative configurations of the Smart PSS delivery scenarios, structured by the various roles assigned to value network actors and the value exchanges and data and information flows among these actors.

6.1.4 Technical Validation

As mentioned in the previous section, the sPS^{2}Modeller is an ADOxx library that can be executed without any licenses. The ADOxx library containing the sPS^{2}Modeller was developed according to the metamodel presented in Figure 31 and conceptually validated by scholars in the servitization field. A second validation was carried out once the sPS^{2}Modeller was ready to use. This validation was done in two stages. In the first stage, the consistency of the conceptual models generated by the modelling toolkit was tested. In the second stage, the applicability of sPS^{2}Modeller in a real industrial setting was tested.

The consistency checks. This first validation stage aimed to verify that the associations between modelling objects conform to the sPS^2 metamodel (Figure 31). The consistency of each modelling view was validated by diagramming models following the associations shown in the sPS^2 metamodel. In other words, it was verified whether it was possible to create the conceptual models as planned in the metamodel. This verification led to the refinement of certain modelling views.

The applicability test. Once it was determined that the modelling tool met the metamodel specifications, its applicability in a real-world design context was tested with practitioners. In order to present the utilization of the sPS^{2}Modeller to the practitioners that collaborated with this thesis, it was decided to create conceptual models associated with a use case known by the professionals involved. This activity aimed to show how conceptual models are created and stored on the sPS^{2}Modeller.

A use case related to an Energy Performance Contract (EPC) in the social housing sector was used to illustrate the utilization of the sPS^{2}Modeller in the offering design process. The gas boiler remote diagnostic service is included in this EPC. This use case is unrelated to the case study presented in Chapter 7 to validate the applicability of the sPS^{2}Risk framework. The EPC was used exclusively to contextualize the employment of the sPS^{2}Modeller in a real-world offering related to the residential heating business. The information on business reports and companies' websites was used as input to create the illustrative models on the sPS^{2}Modeller.

This technical validation consisted of several workshops with elm.leblanc's professionals. The goal of these workshops was to document the feedback from the professionals about the usefulness of the modelling toolkit in their design routines and the intuitiveness of the generated conceptual models. The modelling tool interface and the modelling views were introduced to the manufacturer's professionals in these workshops. Then, the procedure to create the conceptual models was explained. Next, the models made on the sPS²Modeller were explicated. The audience was able to manipulate the modelling toolkit.

The feedback obtained from the professionals concerned the modelling tool's usability, the conceptual models' readability and usefulness, and the modelling procedure's clarity. The managers and professionals involved in this validation stage expressed positive feedback about the modelling approach and its associated toolkit. This positive feedback was based on the modelling toolkit's intuitiveness and the insights that can be inferred from the conceptual models. Thus, sPS²Modeller's applicability in a real design context was validated. The following section details the utilization of the sPS²Modeller during the implementation of the sPS²Risk framework.

6.1.5 Utilization of the sPS²Modeller in the design framework

The modelling tool stemming from the development procedure described in the previous section was conceived to support a set of sPS²Risk framework's tasks, as illustrated in Figure 34. The models created and stored by this modelling tool employ the visual thinking technique by utilizing graphical notations representing the modelling objects. These graphical representations are aimed to facilitate the process of going from the abstract concept of Smart PSS offering to make concrete representations of what is being designed. Thus, discussions that enrich and refine the design objects can be carried out effortlessly to understand the design goals better.

This developed modelling tool is envisioned for a cross-functional team since the design goal is extended from product design to a more extensive scope that involves several internal stakeholders (e.g., tech, sales, marketing, finance, legal). This team's leader, who may be a project manager or a business developer, was called '*project champion'* by Valencia Cardona (2017. p.109). She described this role as "*someone with an overall view of the system and a clear understanding of what the project should deliver.*"
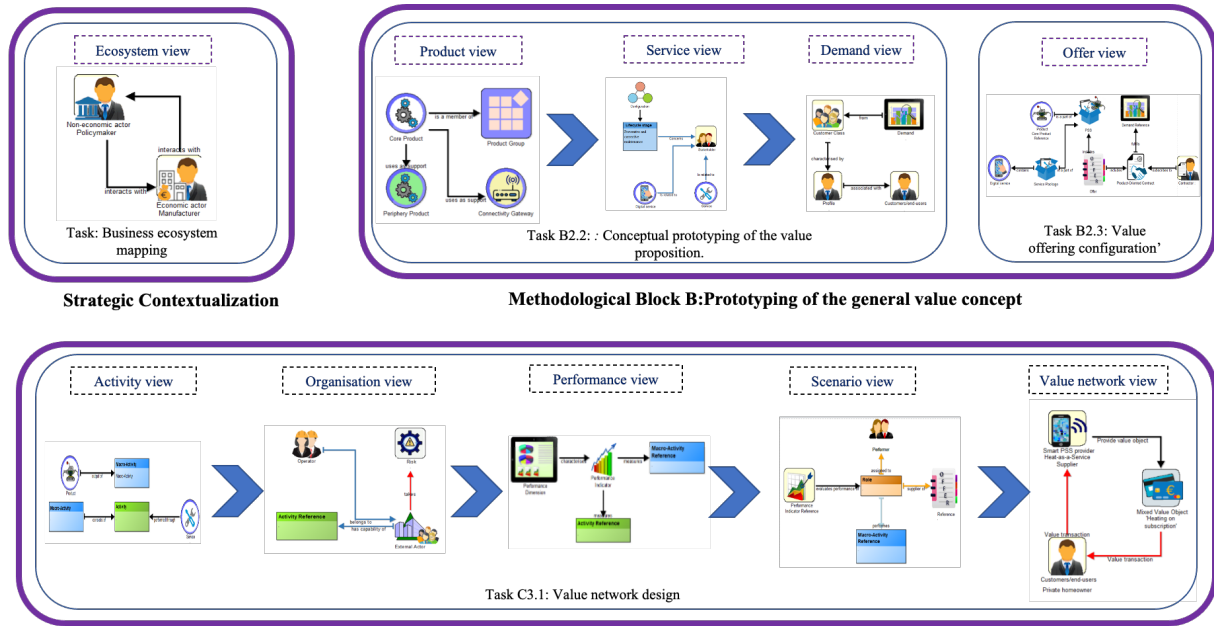
Figure 34. Utilization of sPS²Modeller's modelling views in the proposed design framework.

The professional with the role of 'project champion' is expected to use sPS²Modeller for the following purposes:

(i)   Provide a systemic view of the entire design project and centralize all the knowledge available on the project.

(ii)   Gather and structure the insights collected from the elicitation of key stakeholders' needs step.

(iii)   Represent design alternatives, then facilitate multi-stakeholder decision-making on these alternatives.

(iv)   Facilitate the analysis of value exchange processes amongst business partners.

(v)   Facilitate the identification of innovation risks.

(vi)   Validate the decisions related to the elements of the value proposition design and the value network configuration.

(vii)   Collect the necessary information to simulate the value network actors' profit mechanism in mathematical terms.

The '*project champion*' would be the person leading the proposed design framework's application. Therefore, this leader may use the sPS²Modeller tool during the application of specific tasks that belong to the iterative design loop (Figure 34). As this modelling toolkit is conceived to be straightforward to use, no additional intellectual efforts outside their expertise fields should be necessary from the design team members. In the following subsections, the utilization of the sPS²Modeller in the implementation of the sPS²Risk framework is detailed.

The utilization of the modelling views in the 'Strategic contextualization' step

The sPS²Risk framework proposes carrying out a 'Strategic contextualization' before applying the methodological blocks. The strategic contextualization step and the first methodological block (Figure 18) employ well-established Design Thinking (DT) tools. The templates to apply these tools are easily found in diverse sources. Nonetheless, it was decided to include a modelling view to diagram the firm's current product-based business ecosystem. This activity is part of the 'Strategic contextualization' step and corresponds to the scope of the DT tool called 'stakeholder map' (Lewrick et al., 2020.p.83). The modelling view that enables the creation of this conceptual model was called the '*ecosystem view*.'

The model created in this '*ecosystem*' view allows designers to draw conclusions on two aspects; first, regarding the actors that need to be included in the Smart PSS offering value co-creation process; and second, concerning the external actors that may be a source of unfavourable factors for the offering's success (e.g., rapidly evolving technology, changing market trends, regulations) and the manufacturer's position concerning these factors. This 'ecosystem' model depicts the interactions (e.g., sale of products and services, information sharing, usage of external-owned assets) among actors distinguished between economic and non-economic actors.

The utilization of the modelling views in the methodological block B

The methodological block B involves conceptual prototype creation related to the value proposition components and its associated customer segments. Moreover, the design framework's iterative logic requires undemanding prototypes that can be gradually modified during the framework's application. In this regard, the modelling views 'product view', 'service view,' and 'demand view' were included in the IT tool to support the task '*Conceptual prototyping of the value proposition*,' referenced as B2.2 in section 5.4.

The next task of this methodological block, called '*Configuring the value offering'* referenced as B2.3, involves the value offering drafting. In other words, the description of how the value proposition is commercialized and delivered to the customer. In order to support this task, the '*offer view'* was integrated into the sPS²Modeller. These modelling views and the design information that can be stored via the modelling objects are further described in Table 13.

The conceptual models created in the modelling views and the information stored in the modelling objects serve as cognitive support for innovation risk identification. For instance, on the 'service view' (Figure 35), we find modelling objects such as 'life-cycle stage,' 'service,' 'digital service,' and 'stakeholder.' In the objects 'service' and 'digital service' information such as gain creators and pain relievers can be stored. The discussion of these gain creators may lead the design team to identify potential desirability risks. In sum, based on the conceptual model and the information stored, the design team may identify potential innovation risks during the risk review tasks referenced as B2.5 (Section

5.4), C3.3 (Section 5.5), and E5.3 (Section 5.7). Thus, these discussions are the basis for the decision-making process related to the value proposition design.
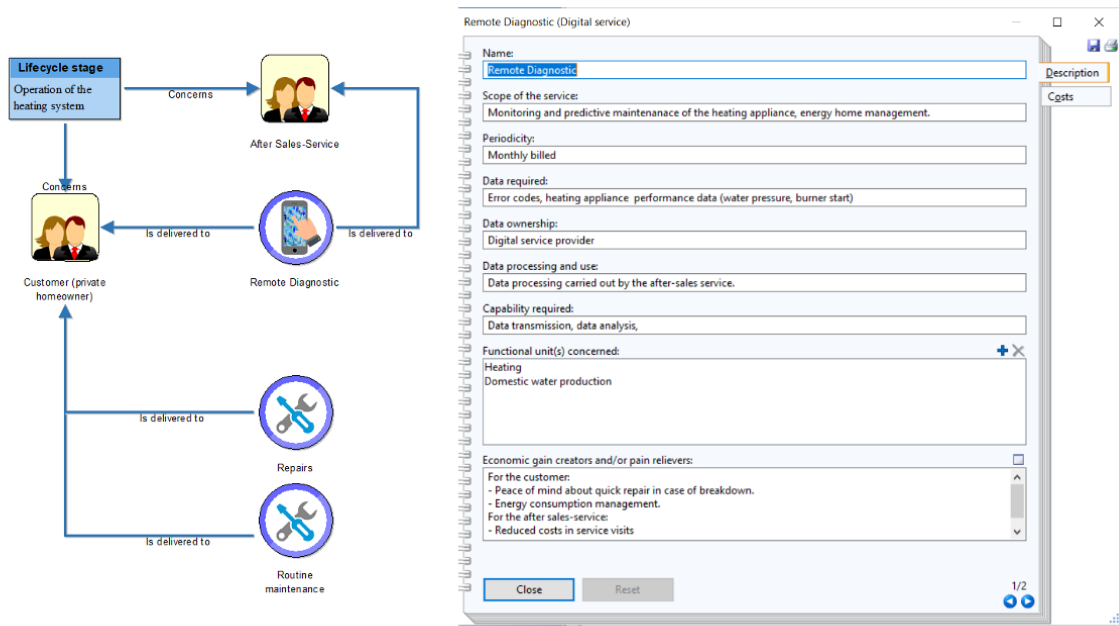
Figure 35. Example of a conceptual model created on the 'service modelling view' and a snapshot of the information stored in the modelling object 'digital service.'

The sPS^2 Modeller as a support to the risk-oriented approach

As mentioned in Section 5.4, an initial risk review is conducted during the application of the methodological block B. Then, this risk review is carried out in the methodological blocks C and E. The main output of this review is a document called '*risk register,*' which is also explained in Section 5.4, specifically in the description of the task *B2.5*. This risk register is updated in the methodological blocks C and E, as described in sections 5.5 and 5.7, precisely in the tasks *C3.3 and E5.3*. This register is a document that must be accessible by all the design team members. For this purpose, a link to a shared document containing the risk document was included in the modelling object 'offer' (Figure 36). This modelling object is found on the 'offer modelling view.'.
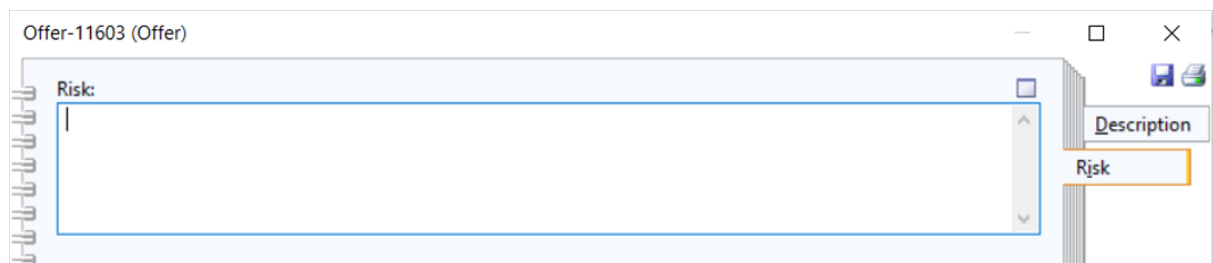
Figure 36. Snapshot of the risk register repository located on the modelling object 'offer' belonging to the 'offer modelling view.'

The utilization of the modelling views in the methodological block C

The last methodological block of the 'iterative design loop,' referenced as Block C and called *'Specification of the value concept,'* requires the creation of conceptual prototypes related to the value network that will deliver the Smart PSS offering. Four modelling views were integrated into the computer-aided tool to support the activities of the task *'design of the value network'* referenced as C3.1 in section 5.5. These modelling views are sequentially employed as described in Figure 34.

The first question addressed in the *design of the value network's* procedure shown in Figure 25 is 'What activities are required to deliver the value proposition?'. Here, the '*activity view'* is employed to display the activities required to deliver the value proposition defined in the methodological block B and represented as a value offering in the *'offer'* modelling view. Then, the '*organisation view'* is used to visualize the answer to the question 'what external actors have the necessary competences and resources to carry out these activities?'.

Once the answers to these questions have been modelled in the abovementioned modelling views, the question 'what performance indicators define the actors' value expectations from the service-oriented value network?' is addressed. These indicators are modelled in the '*performance view.'* Next, two questions arise: 'what service delivery network configurations are possible?' and 'what roles can these actors play in these alternative networks?'. The answers to these questions are represented in the '*scenario view*.' Lastly, the '*value network'* view serves as support to address the question 'what interactions take place in these alternative networks?'. These interactions concern the financial transactions, the data flows, and the flow of products and services. The abovementioned modelling views are further described in Table 14.

The conceptual models generated on the '*value network view*' are the primary input for developing the sPS^{2}simulator. These value network models provide the alternative value delivery scenarios simulated on the sPS^{2}simulator (i.e., the scenarios combining different economic models and service packages). The cost structures and revenue streams for each key actor during the whole life cycle are derived from these models.

Additionally, data about the product and service costs and markups, service frequency, expected product failure rate, and actors' responsibilities are accessible on the modelling objects of various modelling views such as '*product,' 'service,' and 'activity view'* (Table 14). These data are pivotal in defining each key actor's profit formula and establishing the value of the economic models' input parameters. The sPS^{2}simulator is the second computer-based tool developed in this thesis. It is aimed to enable the application of the methodological block D, '*Simulation and decision-making applied to the Smart PSS delivery scenarios*,' detailed in Section 5.6. Further details about the development of the sPS^{2}simulator are presented in Section 6.

Table 13. Overview of modelling views employed in the proposal's methodological block B.

Modelling view	Conceptual model's goal within the proposed framework	Type of innovation risk concerned	Critical questions concerning innovation risk identification	Design information that can be stored in the attributes of the modelling objects
Product Core Product	This view represents the tangible part included in the solution brainstormed during the 'Ideation' task application (B2.1, section 5.4). The core product (manufactured by the focal company) belonging to a product family is associated with periphery products aimed at delivering the solution (e.g., ventilation units, solar panels) and connectivity devices (e.g., smart thermostats, communication modules).	Desirability	• Do the technology used in the tangible part of the solution and the core product's functionalities address the key stakeholders' most important customer jobs, gain points, and pain points (e.g., easy to install in heating retrofit) appliance)? • Is the tangible part of the solution cost-effective, or would it require significant expenses from the customer?	• Concerning the core product: customer and other stakeholders' requirements, differentiation factors, lifetime, mean time between failures (MTBF), mean time to repair (MTTR), downtime, consumables, depreciation, and maximum margin. • Concerning the periphery product: type, operating, and maintenance instructions.
		Feasibility	• Can the core product manufactured by the focal firm be technically integrated with other products that make up the solution? • Can the data necessary to deliver the digital service be collected with the existing product technology?	
Service 	The catalogue of services (digital and non-digital) brainstormed during the ideation task is represented in this view. These services concern one or various key stakeholders identified in the methodological block A. Each service is associated with one of the solution's life-cycle stages, defined during the brainstorming session.	Desirability	• Do the services address key stakeholders' most important jobs, gain, and pain points? • Does the information delivered by the digital service (e.g., energy efficiency) address key stakeholders' jobs, gain, and pain points? • Does the information provided by the digital service target the right stakeholder?	• Concerning the service: concerned functional units, gain creators/pain relievers from the economic, functional, relational, environmental, and social dimensions, service cost structure, and maximum margin. • Concerning the digital service: Scope of the service, payment periodicity, data required, data processing and use, capability required, gain creators/pain relievers from the economic, functional, relational, environmental, and social dimensions functional units concerned, service cost structure, maximum margin.
		Feasibility	• Can the focal firm provide these services with their current capabilities?	
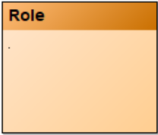
Demand	The global demand associated with the customer segment selected in the *'strategic contextualization task'* performed in the methodological block A is linked to the potential alternative customer classes (e.g., in the B2C and B2B contexts). In turn, these customer classes are linked to customer personas defined in the task A1 *'Understanding key stakeholders' needs'*. If the customers are not the end-users, the latter ones are also characterized.	Desirability	• How large is the market size? • Will enough customers be willing to pay? • What factors can make the market size grow?	• Concerning the demand associated with a customer segment: description, overall estimated demand, demand per period, competitors. • Concerning the customer class: business sector, expected contribution to turnover, contribution to total margin. • Concerning a customer profile: commercial profile, use profile, main customer jobs, main gain points, main pain points. • Concerning the customer/end-user: description, customer jobs, gain, and pain points.
Offer	The demand previously represented is related to the value proposition linked to an economic model (composed of the products and services represented earlier and sold through a contract). In turn, this contract is connected to the customer and the Smart PSS provider. Its content is described in terms of the included service catalogue and the product associated with the service-oriented solution.	Desirability	• Will the customer understand the value offering? • How will the customer experience the value offering? • What alternative options could hinder the customer interest in the value offering (e.g., the traditional upfront payment to buy the product, the subscription to pure contract services)? • What do the competitors do to fulfil the customer needs to be addressed by the value offering? • How can enough customers be reached and acquired?	• Concerning the offer: remedies, terms of the agreement. • Concerning the contract's economic model: contract duration, terms of payment, monthly rent structure, selling price structure, selling price. • Concerning the contractor: customer obligations. • Concerning the Smart PSS provider: limitation of liability.
		Feasibility	• Is the solution legally, socially, and environmentally feasible? • Are the focal firm's current capabilities enough to perform the activities to deliver the Smart PSS solution?	

Table 14. Overview of modelling views employed in the proposal's methodological block C.

Modelling view	Conceptual model's goal within the proposed framework	Type of innovation risk concerned	Critical questions concerning innovation risk identification	Design information that can be stored in the attributes of the modelling objects
Activity	The macro activities associated with core and periphery products (represented in the 'product view'), manufacturing and distribution, and service delivery (described in the 'service view') are linked to specific activities required for Smart PSS delivery.	Feasibility	• Are the focal firm's current capabilities enough to perform the activities? • Are the investments required to implement the digital service affordable for the focal firm? • Is it technically possible to carry out the activities flow (e.g., logistic constraints)?	• Concerning the macro-activities involved in Smart PSS delivery: objective, distinctive technological value-added, service activities excluded from the agreement, frequency of the macro-activity, circumstances that trigger the performance of the macro-activity, value creation activity duration. • Concerning the activities that compose the macro-activities: value creation activity duration, activity cost structure, value creation activity cost. • Concerning the service: scope of the service, periodicity. • Concerning the product: expected upgrades.
		Viability	• Do the service cost structures tend to be volatile in the long term?	
Organisation	The activities identified in the 'activity view' are linked to actors with the resources necessary to perform these activities. These actors may assume risks that the client usually bears.	Feasibility	• Can the focal firm have access to key resources to deliver the solution? • Can the focal firm find the right business partners? • Could the availability of key resources be assured in the long term (e.g., critical skills, knowledge)?	• Concerning external actors: contribution to value creation, perceived value-added, strategic issues, providing costs structure, providing costs. • Concerning human resources: professional skills. • Concerning physical resources: energy cost structure, consumable cost structure, actual capacity, theoretical capacity.

Scenario	The actors required to deliver a value offering are represented and their roles in carrying out the macro-activities involved in service delivery.	Feasibility	• Are our business partners willing to assume the operational risks and responsibilities defined? • Can the business partners ensure the required quality level involved in the value offering agreement? • Do business partners have the capabilities to scale the Smart PSS delivery?	• Concerning the role: descriptive commentary, service fees, payment frequency, handling of non-payment • Concerning the performer: obligations of the performer, penalties applied if the performer cannot carry out the service, penalties applied if the service contract is terminated.
Value network	The value transactions and data and information flow among the business partners involved in service delivery are represented.	Feasibility	• Are there enough win-win conditions to ensure the business partners' commitments?	• Concerning tangible value objects: description, products. • Concerning intangible and mixed value objects: description, basic services, digital services. • Concerning the association 'provides value object': value transaction dimension (financial transaction, environmental, social, functional, relational). • Concerning the data/information flow: description of data/information, source of data/information.

6.2 Economic performance simulation tool

Once the Smart PSS Value Proposition (VP) and the alternative potential value networks to deliver this VP have been established, the remaining central interrogation concerns the Smart PSS offering's 'viability. In other words, the manufacturing firm requires determining if the offering will meet the company's profitability targets. At this point in the design process (i.e., having completed the tasks comprised from methodological blocks A to C), the offering's desirability and feasibility risks have been identified and controlled, and more information about the Smart PSS offering cost structure is available.

As the methodological block D aims to deal with the financial viability interrogation, only the economic dimension is assessed on the developed simulation platform. For this purpose, the models elaborated on sPS²Modeller are used to structure the alternative Smart PSS delivery networks' cost structures and revenue streams. The profitability of these alternative delivery networks over time is simulated on the simulation platform called sPS²Simulator. This profitability analysis is carried out from a multi-actor perspective. The outcomes generated by the sPS²Simulator support the decision-making process, specifically concerning the selection of economically viable service-based offerings. From these outcomes, industrial decision-makers obtain evidence to support their choice of whether to continue with the servitization efforts.

6.2.1 Positioning

In Chapter 4, simulation techniques (discrete-event, system dynamics, and agent-based) were identified as the most common approach employed to assess PSS economic performance during the design phase. Hence, the simulation approach is suitable to estimate the Smart PSS offering's profitability, considering alternative economic models and diverse value network configurations. However, simulation's application in Smart PSS economic assessment is in an infant stage, and in the PSS field, three limitations can be extracted from the literature.

First, a deterministic approach is not suitable in either Smart PSS or PSS economic assessment due to the dynamic behaviour of PSS over time (Phumbua and Tjahjono, 2012; Anke, 2019). This dynamic behaviour implies that a set of input parameters of the economic model will vary during the horizon planning periods. Therefore, this economic assessment needs an uncertainty quantification approach that addresses stochasticity in input parameters.

PSS delivery cost estimation has been addressed in the literature considering uncertainty quantification. However, consideration of revenues uncertainty, the second element of the profit formula, which is strongly linked to the offering's desirability risk, is hardly mentioned in the literature. Consequently, profit uncertainty analysis remains relatively unexplored in PSS and Smart PSS design. This type of analysis can assist the industrial firm in mitigating the viability risks that could lead the company to fall

into the digitalization paradox trap. In other words, a situation in which the industrial firm does not obtain enough profits from the investments made to sell Smart PSS offerings.

Second, the literature has widely acknowledged that PSS and Smart PSS delivery entails the involvement of multiple actors that contribute with different types of resources and competences. Therefore, Smart PSS's successful implementation relies on the profitability obtained for each actor from their operations in service delivery. Failure to obtain the expected profitability may cause a pivotal actor to withdraw from the service delivery network. Hence, the Smart PSS' feasibility would be severely compromised. Despite this significant characteristic of servitised offerings, most economic assessments presented in the literature report their evaluations from a single actor or a dyadic perspective. Consistently with Smart PSS characteristics, a multi-actor view, including the customer and critical business partners, is needed to ensure the viability of this offering.

Third, the economic assessment of service-oriented offerings must cover the activities performed by multiple actors during the whole all-inclusive solution's life cycle. Accordingly, two elements turn out to be crucial in financial benefit estimation in the Smart PSS design context: (i) the definition of all the activities involved in Smart PSS delivery and their subsequent cost objects, and (ii) cost and revenue attribution among value network actors.

These three gaps were addressed altogether in this thesis by developing a computer-aided tool tailored to the case study presented in Chapter 7. Although this simulation platform was customised for this case study, the development and validation method shown in the following sections is generic and applicable in other use cases. The IT tool presented in this section estimates a set of economic performance indicators for each of the critical Smart PSS value network actors (e.g., accumulated profit). This estimation considers the variability of a group of input parameters over a defined horizon planning.

These parameters were refined using the models created by the modelling tool presented in the previous section. The following section describes the method applied to develop and validate the sPS²Simulator. An overview of reported IT tools in the literature to predict PSS and Smart PSS viability is presented in Table 15. An overview of the IT tools aimed at assessing the performance of PSS and Smart PSS offerings that can be found in the literature is shown in Table 15.

6.2.2 Simulation tool development and validation

The sPS²Simulator aims to support the operationalisation of the sPS²Risk framework's methodological block D, as detailed in the following subsection. Unlike sPS²Modeller, which can be applied to any use case, this quantitative simulator must be customized to the case study. This customization is because profit estimation relies on factors such as the value proposition content, the financial transactions among value network players that vary depending on the value proposition, and the service packages included in the contract's scope. The development and validation process of this IT tool is depicted in Figure 37.
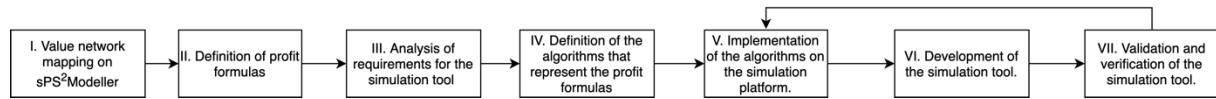
Figure 37. Development and validation process to build the sPS²Simulator.

Table 15. Overview of PSS and Smart PSS computer-aided economic performance assessment tools.

Design filed/Economic assessment simulation tool	Tool description	Case study	Actors' perspective	Economic models	Life-cycle stages included	Inputs	Uncertainty analysis application
PSS field/ HLA RTI: Alix and Zacharewicz (2012).	Distributed PSS Modelling Environment that interfaces components of the PSS Models and other actors in HLA compliant Federation.	B2C: Toys	- Clients - Producers - Sellers	Product-, and use-oriented	- Manufacturing - Sale/rent - Warranty -Test/clean/repair - Dispose/recycle	- Seasonal demand forecast - Playtime, pause time - End-of-interest - Broken toy incidents	Not mentioned
Smart service/ PSSWeb-based application: Anke (2019).	Web-based tool prototype.	Not reported	Service provider	Not reported	Not reported	Service variable costs	Not mentioned
PSS field/ PS3A–PSS Analyzer: Medini et al. (2021).	Web-based software platform in PHP (Hypertext Pre-processor Language)	B2B: Industrial cleaning	- Solution provider - Battery provider - Customer	Product-, result-, and use-oriented	- Customer co-design - Robot manufacturing - Installation services - Equipment cleaning - Maintenance	- Unit cost of different activities - Service frequency - Margin rate of product and services - Yearly demand volume - Contract duration.	No

I.   *Value network mapping on sPS²Modeller*

This stage included the analysis of the alternative value network prototypes created on the '*value network'* modelling view (See section 5.5, task C3.1). These conceptual models were used to extract the monetary value exchanges amongst the value network actors from each alternative value network. This monetary value exchange representation enabled the definition of each key value network actor's cost structures and revenue streams during the whole Smart PSS life-cycle. Consequently, the alternative 'value network' models are the primary input for developing the IT tool that operationalises the methodological block D.

Figure 6.10 illustrates the employment of the 'value network' modelling view to represent the financial transactions that take place in the traditional product-based sale of residential heating appliances. From this model, it can be inferred that the heating appliance manufacturer's revenue stream is the sale of the appliances to the wholesalers. Moreover, it can be deduced that the manufacturer's cost structure is

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associated with direct (e.g., labour manufacturing, direct materials) and indirect costs (e.g., design costs, utilities) to manufacture and distribute the appliance. Based on this information, the profit formula elements for each key actor can be defined.
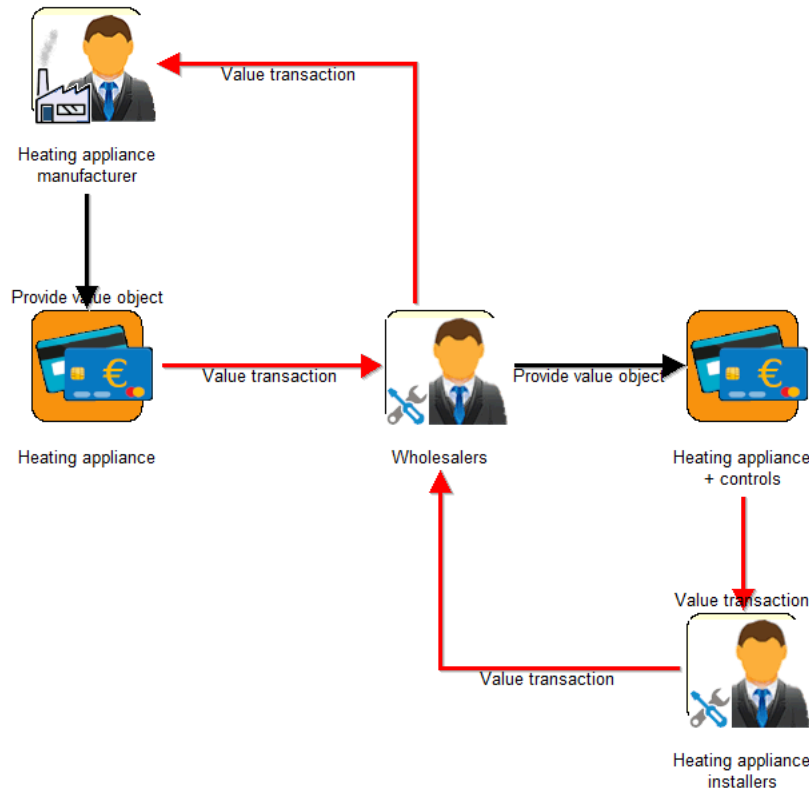
Figure 38. Example of a value network conceptual model created on the sPS^{2}Modeller.

II.   *Definition of profit formulas*

The profit formulas must be defined to simulate the profitability stemming from the delivery of the Smart PSS offering. These formulas are defined for each key value network actor. The incoming value exchanges depicted in the 'value network' model represent the revenue streams for the actor, while the outgoing value exchanges represent their cost objects. These revenue streams and cost structures must be formulated in terms of input parameters to be implemented on a simulation platform.

To illustrate this stage, we consider the value flows depicted in Figure 38. This conceptual model shows that the installer's revenue stream is associated with the sale of the heating appliance to the customer and the service fee for the appliance installation. In turn, the cost objects linked to the installer are associated with the price of the heating appliance at the wholesaler where the installer purchases the appliance and the material and labour cost involved in the installation service. These incoming and outgoing value flows are translated into equations.

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For the sake of simplicity, we can express the equations concerning the installer's total revenue and total costs as follows:

$$IR_i = TCI_i * IM_i \quad (6.1)$$

$$TCI_i = PPI_i + CIS_i \quad (6.2)$$

$$PPI_i = (PPW_i + PCH_i) * WM_i \quad (6.3)$$

Table 16. Notations used in the cost and revenue equations from the installer's perspective.

Notation	Description
IR_i	Installer revenue for the installation of the appliance of reference i
TCI_i	Total cost for the installer for the installation of the appliance of reference i
PPI_i	Purchase price of the heating appliance of reference i for the installer
IM_i	Installer's markup on the installation of the appliance of reference i
CIS_i	Installation service cost of the appliance of reference i
PPW_i	Purchase price of the heating appliance of reference i for the wholesaler
PCH_i	Purchase price of the connectivity hardware for the appliance i for the wholesaler
WM_i	Wholesaler's markup on the installation of the appliance of reference i

Once the equations representing each key stakeholder's cost and revenue streams have been formulated, they must be translated into algorithms that enable their implementation on the simulation platform. These equations must include all the activities involved during the whole Smart PSS offering's life cycle, as an actor can have multiple roles during the different life cycle stages. For instance, installers can also uninstall the appliance when the customer contract ends in addition to the installation service. The resulting list of input parameters identified from the definition of the profit formulas is used to plan for the collection of the value of these parameters, as described in the task D4.1 (Section 5.6).

III. *Analysis of requirements for the simulation tool*

The definition of the requirements to develop the economic performance assessment tool was guided by two inputs. The first input is the performance indicators defined in execution of the task C3.1 (Section 5.5) and modelled on the 'performance modelling view' of the sPS[2]Modeller (Figure 37). The simulation tool must provide the prediction of these performance indicators over a simulation horizon set by the tool's user. Thus, this modelling view aids in defining the calculations required to display the KPIs.
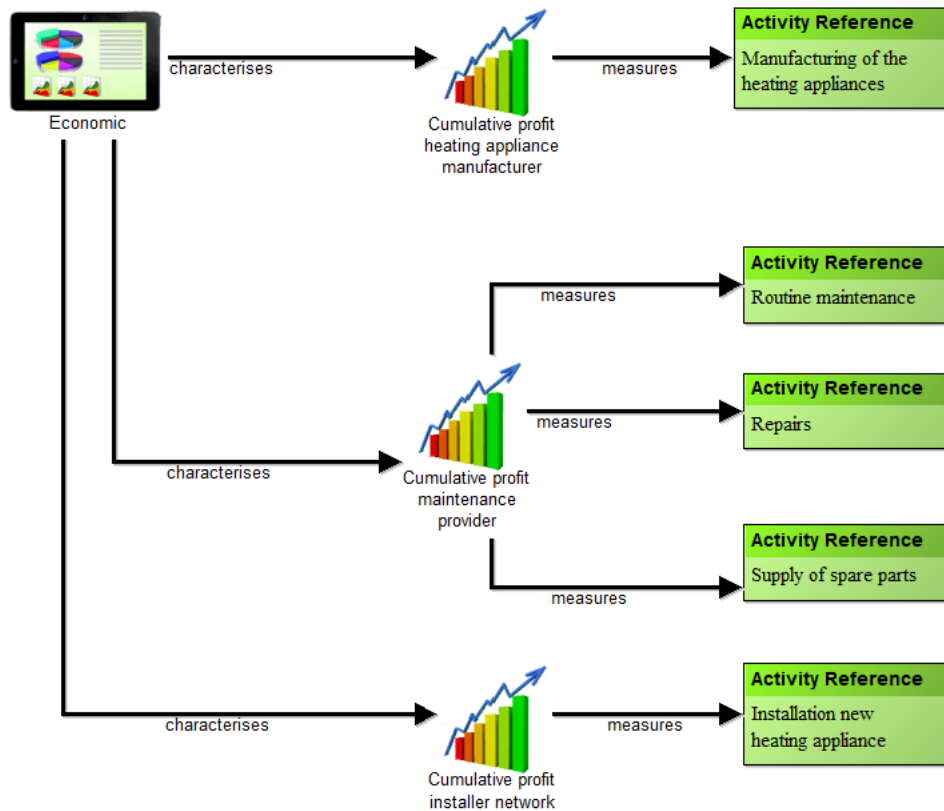
Figure 39. Example of a performance indicator conceptual model created on the sPS²Modeller.

The second input is the economic analysis objectives set during the execution of the task D4.1 (Section 5.6). These objectives convey the data visualization needs. Consequently, these objectives are crucial to designing the dashboard included in the simulation tool. In sum, three aspects related to the simulation tool requirements were identified: (i) concerning the input parameters that must be entered by the user, (ii) the consideration of the variability of the value of these input parameters to represent the uncertainty associated with a set of 'dynamic' economic model inputs, (iii) and data output display in the user interface.

IV.   Definition of the algorithms that represent the profit formulas

Once the profit formulas associated with each alternative have been established, these formulas must be defined to guide the simulator developers. To that end, flowcharts are used to communicate how these profit formulas must be implemented on the simulation platform. For each alternative value delivery scenario validated during the task *C3.1,* a flowchart describing all the activities involved and the distribution of costs and revenues for each actor must be made, as illustrated in Figure 40.

These flowcharts constitute the backbones of the simulation tool. A traditional PSS (i.e., no digital services included in the service package), and product-oriented economic subscription are displayed in the example. For the most part, this flowchart is similar to the flowcharts elaborated for the product-

oriented subscriptions, including Smart PSS service packages, and the use-oriented subscriptions, including either PSS or Smart PSS service packages.

Backbone of the sPS^{2}Modeller for product-oriented economic models
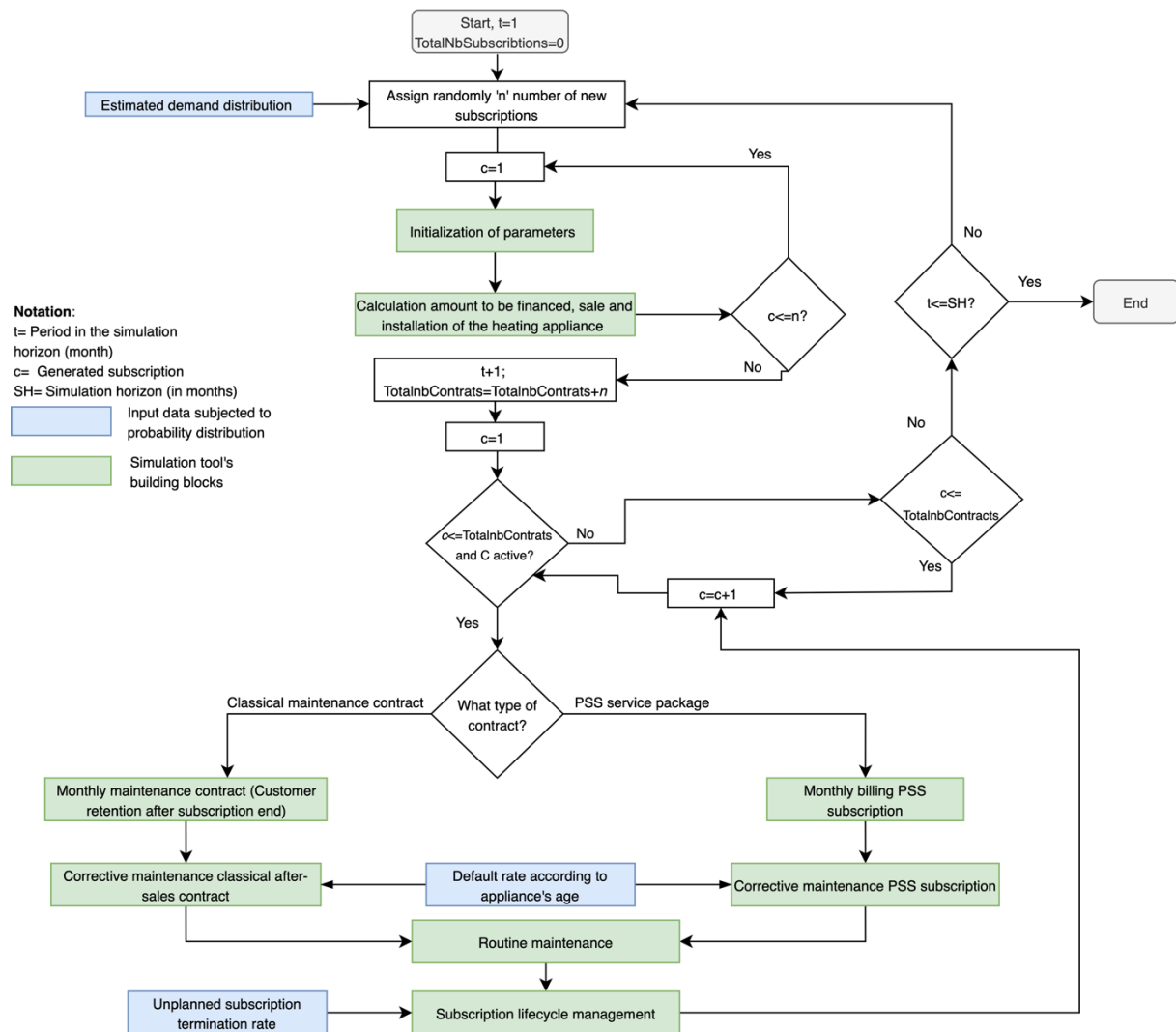
Figure 40. Flowchart describing the activities involved in product-oriented economic models.

From the diagramming of these flowcharts for each alternative value network of the case study presented in Chapter 7, it can be observed that a group of activities appear in every flowchart. This is explained as there are inherent services to the residential heating business, such as heating appliance installation. Consequently, 'building blocks' that cover these activities and their associated monetary value exchanges were created.

Among these building blocks, we can mention: (i) the subscription billing (i.e., the contract between the customer and the Smart PSS provider), (ii) the appliance installation, (iii) the mandatory routine maintenance, (iv) the repairs and the supply of spare parts, and (v) the management of the subscription's end. Figure 41 displays the activity flow associated with the mandatory routine maintenance. In this flowchart, the algorithm verifies whether a routine maintenance operation must be planned for each

active subscription. This decision is based on the subscription's start date and the maintenance frequency.
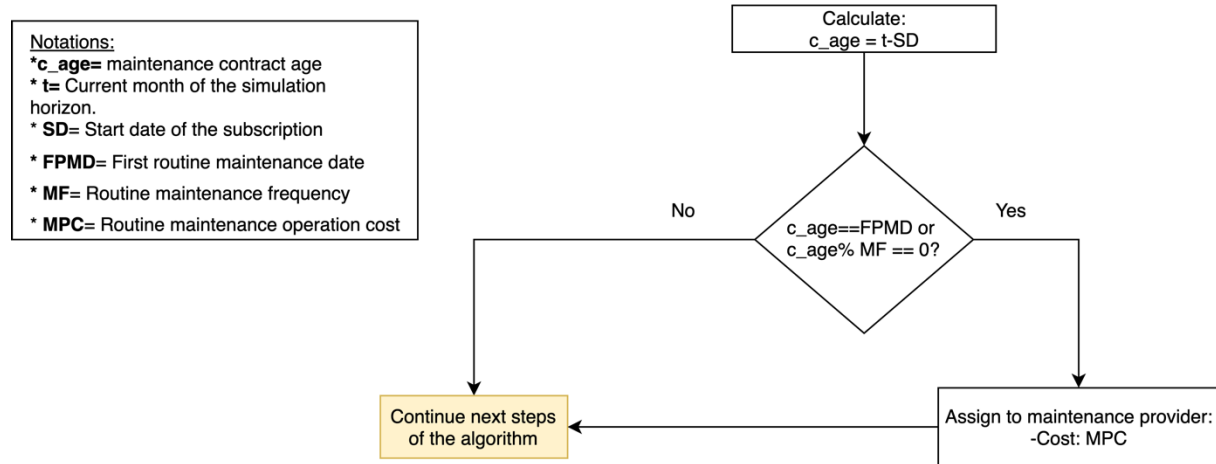
Figure 41. Flowchart displaying the heating appliance's routine maintenance activities.

In order to enable the economic performance assessment of each alternative value delivery network, these building blocks are aimed to be reused on the simulation platform. These flowcharts also display the parameters that must be entered by the user and the calculations made to obtain the assigned costs and revenues. For example, it can be identified from this flowchart that the maintenance frequency according to the current regulations vary for gas boilers and heat pumps. Therefore, the simulation tool must enable the user to enter a differentiated value for this input parameter depending on the type of heating appliance.

V. Implementation of the algorithms on the simulation platform

These flowcharts were verified and validated to ensure their accuracy with the 'value network' conceptual models. From these flowcharts, pseudocodes were written in natural language. The creation of these pseudocodes was aimed to facilitate the implementation of the algorithms mirroring the alternative value delivery scenarios of the case study presented in Chapter 7 on the simulation platform. It is important to mention that the sPS^{2}Modeller was conceived to be a mock-up of a more sophisticated IT tool that could be operationalised in the activities of elm.leblanc. Thus, these algorithms were implemented in Visual Basic using the VBA programming language. Visual Basic was selected as the simulation technical environment because of its ready availability and practitioners' familiarity with its graphical user interface.

For the case study presented in Chapter 7, twelve Value Delivery Scenarios (VDS) were implemented on the sPS^{2}Modeller. These VDS are the result of combining a service package (e.g., PSS and Smart PSS) and an economic model. Each service package and economic model has a set of particularities that must be included in the simulation platform (e.g., concerning the appliance's ownership and the payment

structure of the service packages). The implementation of the algorithms defined in the previous stage enabled the development of the sPS^{2}Modeller as described in the following stage.

VI. *Development of the simulation tool*

The implementation of the algorithms in visual basic led to the final artifact: the sPS^{2}Modeller. A Graphical User Interface (GUI) was conceived in this stage to enable the operationalisation of this final artifact. This GUI addressed the entry of the economic models' input parameters and the numerical and graphical visualisation of the simulation's outcomes, further described below. Correspondingly, a user interface was created for each economic model. In this interface, the user can choose the service packages to be simulated. For instance, hypothetically, considering the case of four service packages included in the value offering modelled in the '*offer view'* (See section 5.4, task B2.3), the user can either simulate a combination of these service packages delivered under the same economic model, or a scenario including only one of these service packages.

The input data interface: In this interface associated with a specific economic model (e.g., leasing or result-oriented), in addition to the service packages to be simulated, the user can enter the value of a broad set of input parameters. Concerning the simulation run, the user can fix the simulation horizon expressed in months, the number of iterations to perform in the simulation run, the product references to be included in the subscription, and the share of each service package on the total number of sold subscriptions. Here, we consider as subscription the all-inclusive contract between the customer and the service provider.

The list of the economic model's input parameters required for the simulation was established based on the profit formulas defined in the second stage of this development process (Figure 37). These mandatory input parameters required to run the simulation can be grouped as follows:

(i) Subscription-related inputs: subscription period in months, subscription renewal probability, subscription price.

(ii) Product-related inputs: monthly probability of a subscription sale that includes a specific product reference, product lifetime, manufacturing and distribution cost of each reference, each key actor's markup on the product, each key, actor's product purchase cost, warranty time.

(iii) Market volume-related inputs: new subscriptions sold per month over the time horizon, churn rate.

(iv) Inputs exclusive to the economic model to be simulated: these inputs represent particularities of each economic model addressed in the case study (Chapter 7).

(v) Maintenance-related inputs: Routine maintenance frequency, failure rate depending on product's age over the simulation horizon, probability of occurrence of repairs categorized

by severity, travel, and labour maintenance operations' costs, margins on maintenance operations, spare part costs, margin on spare parts.

(vi) Inputs related to services performed by external actors: costs concerning services performed by external actors such as customer acquisition, product installation, and product uninstallation/disposal and the margins on these costs.

(vii) Digital service-related inputs: connectivity hardware cost, monthly data analytics costs per customer, additional customer fee for the service, and expected savings in maintenance operations.

All these input parameters were organised in the user interfaces where users can enter the value of these input parameters. Figure 42 shows a snapshot of this interface. This tool enables the execution of the task D4.3, called '*Economic analysis and uncertainty assessment'* (Section 5.6). Among the aims of this task, we find the study of the impact of the variation of input parameters on the economic model's outputs (e.g., the total costs from the perspective of a key actor). These user interfaces enable the users to modify the input parameters to extract the KPIs simulated by the IT tool. Then, these outputs can be compared and analysed as described in this task.

In the upper part of Figure 42, we find the interface to register the parameters related to the simulation run (e.g., the number of iterations), the references of the products included in the subscriptions, and the distribution of their sales. These input fields are also related to the distribution of PSS and Smart PSS subscriptions for the simulated economic model. Furthermore, we find parameters representing the dynamic factors described by Phumbua and Tjahjono (2012), such as the customer cancelation rate and the market volume of the all-inclusive subscriptions. In the lower part of Figure 42, we can observe economic parameters associated with each product reference included in the all-inclusive subscriptions. For the case study presented in Chapter 7, gas boilers and heat pumps were included in the subscriptions. The input fields listed in this tab are associated with parameters concerning costs and margins from the perspective of the key value network actors (heating appliance manufacturer, maintenance provider, installer network, and service provider).

Fixed values

Simulation length (months). Max 150	84

FPMD= Month of First preventive maintenance for Boilers (Heat pumps fixed to 24)	10
PSS Contract duration (Years). Max 15	5
Probability Renew Contracts After 5 years	0,6
Probability of adopt or keep at year 5th a remote sensor	0

Category of possible subsidy to customers	Probability
Category 1	0,3
Category 2	0,4
Category 3	0,3

Only maintenance contract after PSS contract ending	Probability
Preventive maintenance	0,6
Preventive and corrective	0,3
Premium	0,1

Type of finance and Maintenance contract (PSS)	Probability
Contract A	1
Contract B (Smart sensor)	0

Number of iterations	1
Last simulation total duration time	881,07 Secs / 15 Min
Histograms Interval's number	5

Simulate — ● Uniform distribution ○ Normal distribution

		Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Bounds new contracts number (Monthly)	Minimum Value	10	60	85	120	160	204	254	304	358	412	412	412	412	100	100	100
Generation of contracts year by year of simulation	Maximum Value (Max 350)	60	85	120	160	204	254	304	358	412	465	465	465	465	120	120	120
Normal Distribution	Average demand (Max 300)	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
	Standard deviation	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Cancelation rate by year		0	0	0,01	0,01	0,01	0,01	0,01	0,01	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3

Boyler Type	Sale Probability																
Boiler Ref1	0,3	0,18	0,22	0,24	0,30	0,35	0,40	0,43	0,45	0,17	0,45	0,45	0,20	0,20	0,20	0,20	0,20
Boiler Ref2	0,2	0,18	0,22	0,24	0,30	0,35	0,40	0,43	0,45	0,17	0,45	0,45	0,20	0,20	0,20	0,20	0,20
Boiler Ref3	0,15	0,18	0,22	0,24	0,30	0,35	0,40	0,43	0,45	0,17	0,45	0,45	0,20	0,20	0,20	0,20	0,20
Boiler Ref4	0,1	0,18	0,22	0,24	0,30	0,35	0,40	0,43	0,45	0,17	0,45	0,45	0,20	0,20	0,20	0,20	0,20
Heat Pump Ref 1	0,1	0,18	0,22	0,24	0,30	0,35	0,40	0,43	0,45	0,17	0,45	0,45	0,20	0,20	0,20	0,20	0,20
Heat Pump Ref 2	0,08	0,18	0,22	0,24	0,30	0,35	0,40	0,43	0,45	0,17	0,45	0,45	0,20	0,20	0,20	0,20	0,20
Heat Pump Ref 3	0,05	0,18	0,22	0,24	0,30	0,35	0,40	0,43	0,45	0,17	0,45	0,45	0,20	0,20	0,20	0,20	0,20
Heat Pump Ref 4	0,02	0,18	0,22	0,24	0,30	0,35	0,40	0,43	0,45	0,17	0,45	0,45	0,20	0,20	0,20	0,20	0,20

(Failure Rate by year of boiler use)

Variable	Gas boiler references 1	2	3	1	2	3	1	2	3	1	2	3
Heating appliance and installation price+ Administration costs	€ 4 000,00			€ 4 500,00			€ 5 000,00			€ 5 200,00		
Subsidies (SI)	€ 2 650,00	€ 2 250,00	€ 725,00	€ 2 650,00	€ 2 250,00	€ 725,00	€ 2 650,00	€ 2 250,00	€ 725,00	€ 2 650,00	€ 2 250,00	€ 725,00
Amount financed by the financing supplier (Faij)	€ 2 650,00			€ 2 650,00			€ 2 650,00			€ 2 650,00		
Monthly payment by the client for financement of the installation of the heating (MPFij)	€ 25,00	€ 33,00	€ 62,00	€ 35,00	€ 42,00	€ 71,00	€ 44,00	€ 52,00	€ 80,00	€ 48,00	€ 55,00	€ 84,00
Monthly price for the maintenance contract (MCP) (Margin included for the service provider)	€ 12,00	€ 12,00	€ 12,00	€ 12,00	€ 12,00	€ 12,00	€ 12,00	€ 12,00	€ 12,00	€ 12,00	€ 12,00	€ 12,00
Monthly payment for the default insurance contract (ICP) ((Margin included for the service provider)	€ 3,00	€ 3,00	€ 3,00	€ 3,00	€ 3,00	€ 3,00	€ 3,00	€ 3,00	€ 3,00	€ 3,00	€ 3,00	€ 3,00
Monthly payment from the client (PMBij)	40 €											
(MDCi= Manufacturing and distribution cost of gas boiler reference i	1 400 €			1 600 €			1 800 €			2 000 €		
Manufacturer's margin on selling price of gas boiler boiler (Mmi)	0,30			0,30			0,20			0,20		
Wholesaler's margin on selling price of gas boiler reference i for the installer (Mwi)	0,20			0,20			0,15			0,15		
Installation cost of gas boiler i for the installer (labour, travel and material costs) ICi	400 €			420 €			480 €			520 €		
Installer's margin on purchase costs of heating system and installation fees (Imi)	0,30			0,30			0,30			0,30		
Thermostat cost	120 €											
Thermostat cost + Smart sensor hardware	150 €											
Smart sensor Monthly Payment	6 €											
Smart sensor installation + Smart sensor hardware (Price for existing customers that contract the smart sensor functions)	50 €											
Monthly data analytics costfor maintenance provider(Cost of analyzing data from boiler sensor incoming data)	5 €											
Service provider's administration costs (ADC)	200 €											
Maintenance contract monthly cost for the service provider (MCP)	10 €											
Insurance contract cost for the service provider (ICP)	3 €											
Monthly revenue maintenance contract for the maintenance provider (MRMC) (Financing and maintenance contracts)	10 €											
Margin for the maintenance provider from the maintenance contract (MMP)	0,20											
Estimated monthly cost for the maintenance provider (MCMC)(Financing and maintenance contracts)	8 €											
Cost penalty for the client (CP)	150 €											
Cost for the preventive maintenance operation (Travel, Labor, Etc.)	55 €											
Monthly price of new maintenance contract of type i (NMCP1)	10,32 €											
Monthly price of new maintenance contract of type 2 (NMCP2)	19,87 €											
Monthly price of new maintenance contract of type 3 (NMCP3)	12,00 €											
Maintenance Frequency	12	12	12	12	12	12	12	12	12	12	12	12

Info: Cells in gray color will take the value of their next input cell to the left

Figure 42. Snapshot of the data input interfaces of the sPS^{2}Simulator.

In addition, a set of stochastic variables were introduced in the computing procedure. These stochastic variables specifically concern the market volume and the product failure rate. The latter impacts the number of repairs performed over the simulation period and the number of spare parts sold. Concerning the market volume, the data input interface allows the tool's user to choose between a uniform or normal distribution to create the number of new subscriptions sold during each month. Therefore, each simulation iteration generates a different number of sold contracts considering the selected probability distribution and the value of the input parameters concerning the market volume.

The numerical output data interface: Once the user enters the value of the required input parameters, the sPS^{2}Simulator computes the KPIs and metrics modelled in the 'performance view' of the sPS^{2}Modeller results are recorded on the IT tool. These KPIs and metrics (revenues, costs, and profits) are computed for each key value delivery actor. In the case study presented in Chapter 7, five roles were identified as key: the heating appliance manufacturer, the installer network, the service provider (e.g., the actor that sells the subscription to the customer), the maintenance provider, and the customer. The results of these metrics and KPIs are presented to the user in two different forms. First, they are displayed month by month over the simulation horizon set by the user. This allows the sPS^{2}Simulator's users to track the monthly evolution of these figures. These figures are aggregated on an annual basis and presented to the user. Revenue and cost sources are differentiated for each actor.

To illustrate this revenue and cost breakdown, consider the heating appliance manufacturer's role. For the sake of simplicity, this actor's revenues were differentiated between those originating from the sale of heating appliances and those from the sale of spare parts. The manufacturer's costs were also broken down into these same categories. The total profit was calculated based on the aggregated revenues and costs.

Among the metrics, we find the number of repairs and routine maintenances carried out, the heating appliances sold thanks to the subscription sales, the number of spare parts sold, and the number of active subscriptions. Each key actor's revenues, costs, profits, and other metrics are also aggregated into an annual figure, displayed in an additional interface. The sPS^{2}Modeller shows these monthly and yearly outcomes for each simulation iteration, and it also aggregates the results of the iterations into a single table (Figure 43).

Figure 43. Snapshot of the numerical data output interfaces of the sPS^{2}Simulator.

The numerical output data interface: A dashboard was included in the sPS^{2}Simulator to provide the decision-makers with insights into the economic performance of each simulated value delivery network. This dashboard is mentioned in task D4.2 and is aimed to enable the visualization of the simulation results (Figure 44). This interface displays each key value network actor's total costs, revenues, and profits. The annual values of these KPIs were plotted in graph bars, while the monthly values were plotted in curve charts.
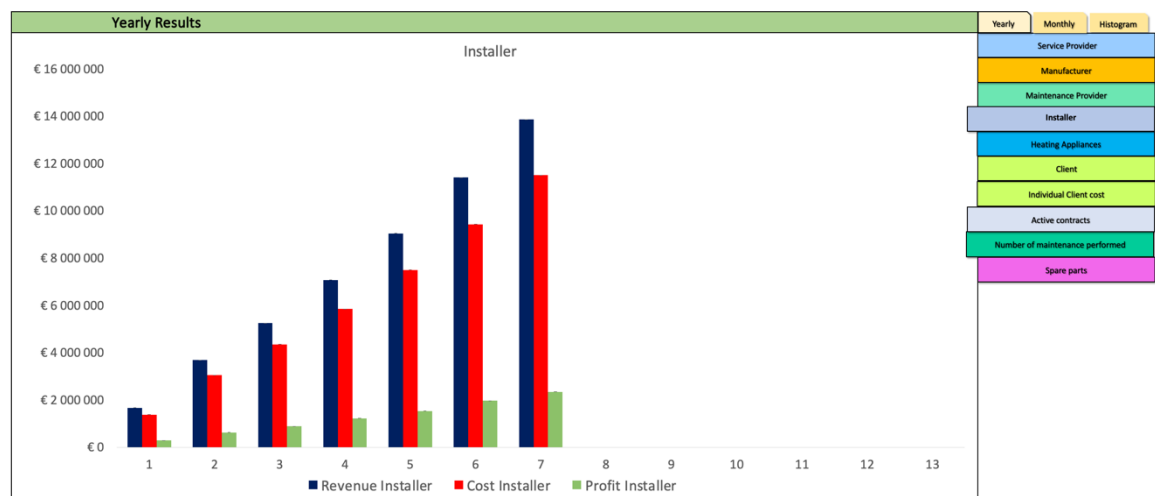
Figure 44. Snapshot of the dashboard included on the sPS^{2}Simulator displaying the key KPIs for the installer network.

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Other metrics calculated over the simulation were also included in the dashboard. Among these metrics, we find the number of active subscriptions, the number of routine maintenance operations performed, and the number of spare parts sold. The dashboard also displays histograms that trace out the structure of the distribution of the cumulative profit for each key value network actor (Figure 45). These histograms are plotted based on the simulation outputs of each iteration of the simulation run. Decision-makers can use these histograms to quantify the aggregated uncertainty of the profitability of each value delivery scenario over the simulation horizon set by the tool's user.
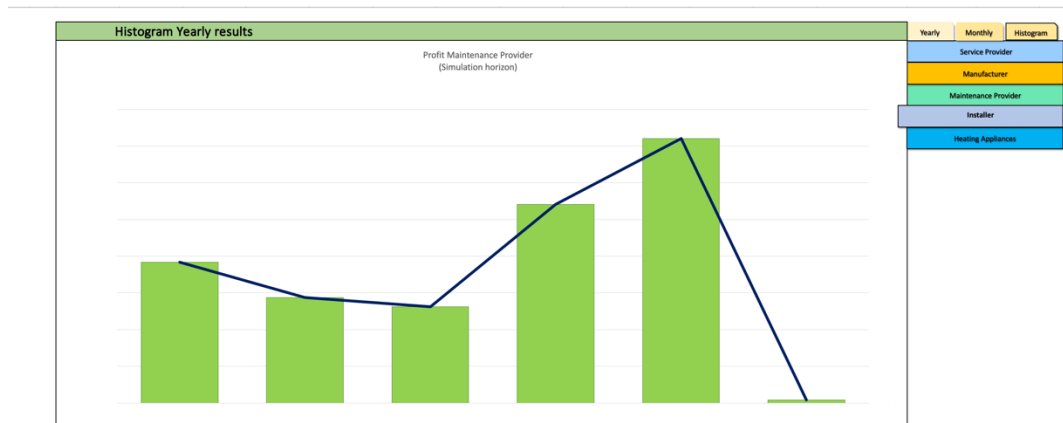
Figure 45. Snapshot of the histogram included in the dashboard depicting the expected profitability from the maintenance provider's perspective.

These user interfaces were conceived to be readily interpretable by the practitioners. Once a final artifact was ready to use, the reliability of its simulation outputs was tested.

VII.   Validation and verification of the simulation tool

Specific tests were carried out to identify possible inconsistencies. These tests were aimed to verify the accuracy of the simulation results provided by the sPS^{2}Simulator (e.g., verifying if the expired subscriptions were stopped being considered in the planning of routine maintenances). These tests led to the refinement of the code used to implement the algorithms.

In the development of this economic performance assessment tool, it was noted that particular attention must be paid to the management of the subscriptions' life cycle. For example, the simulation tool must integrate aspects such as the subscription cancellation by the customer, customer default, the planning of routine maintenances in compliance with the regulations, the evolution of the heating appliance's age and its impact on the repairs needed, and the expected savings from the operation of the Smart PSS offering. All these aspects, among several others, must be tested and validated before making the tool operational for the application of the methodological block D of the sPS^{2}Risk framework.

The sPS^{2}Modeller's operation was introduced to the practitioners that collaborated on this thesis. This was aimed at obtaining their feedback about the tool's usability. These practitioners validated the tool's

convenience within their offering design routines. In the next section, the application of the sPS²Modeller in the tasks corresponding to the methodological block D is described.

6.2.3 Utilization of the simulation tool in the design framework

The sPS²Simulator was developed to enable the operationalization of this task D4.3 called '*Economic analysis and uncertainty assessment.*' (Section 5.6). This simulation tool aims to provide the design team with better decision-making capabilities concerning selecting the most advantageous value network(s) to implement the delivery of the Smart PSS offering. These delivery networks are combinations of products, services, and players involved in delivering the Smart PSS offering under a specific classical PSS economic model (product, use, and result-oriented). Moreover, the output simulation data can be helpful in the decision-making processes that concern other dimensions such as pricing and resource capacity planning for service delivery. For example, suppose the simulation outputs show that the expected number of maintenance operations evolve, and a given service level to be reached is identified. In that case, it is possible to anticipate the required workforce level.

The 'project champion' mentioned in Section 6.1.5 may use the simulation tool for two purposes. First, to provide internal stakeholders with insights about the potential monetary value captured from the Smart PSS commercialization. Second, to ensure the commitment from external stakeholders by presenting estimations about the win-win economic outcomes derived from their participation in the Smart PSS delivery. In addition to the 'project champion,' other users can use the simulation tool to perform what-if analyses. In these analyses, design team members examine the impact of input parameter variation on the outputs that represent the likely financial performance of the economic model being simulated. For instance, the effect of rising a particular cost event on the accumulated profits for all the actors involved in Smart PSS delivery can be examined.

No technical skills are needed for users to utilize the simulation tool. However, implementing the algorithms that replicate the Smart PSS value network scenarios in the technical simulation environment requires programming skills. In this regard, multiple simulation software programs such as AnyLogic and Arena are available. However, the focus of the methodological block D was the financial viability analysis of the Smart PSS offering and not the physical resource capacity. Therefore, the use of these simulation software programs was not integrated into the sPS²Risk framework's application. Besides, the licenses and the required knowledge to use these programs may hinder their immediate implementation in the design routines of the company that collaborated in this thesis.

6.2.3.1 The sPS^{2}Simulator tool as support to operationalize the '*Economic analysis and uncertainty assessment*' task (D4.3)

As the 'scenario analysis' technique is employed in this task, the design team must define an experience plan. These scenarios include the alternative value delivery networks considering different input parameter settings that represent the 'what if' questions' assumptions. To illustrate this, Figure 47 depicts a simplified experience plan. Two scenarios are considered in this plan. Each scenario contains a set of fixed input parameters' values agreed by the design team that represents the specific assumptions of the scenario.

In total, 18 alternative value delivery scenarios must be tested on the sPS2Simulator according to this experience plan. The first scenario contemplates an increasing demand for service-based subscriptions over the simulation period. Conversely, the second scenario reflects a decreasing demand over the same period. Each scenario considers the classical three PSS economic models. Three combinations of two service packages are included in each economic model (the exclusive commercialization of either service package 1 or 2 and the concurrent commercialization of both service packages). Each simulation run implies that the tool's user enters the input parameters corresponding to each 'scenario' previously defined, runs the simulation, and verifies and extracts the simulation outputs.

Scenario 1: Increasing demand for subscriptions over simulation horizon.

I. Product-oriented economic model
- Service package 1
- Service package 2
- Service package 1 + Service package 2

II. Use-oriented economic model
- Service package 1
- Service package 2
- Service package 1 + Service package 2

III. Result-oriented economic model
- Service package 1
- Service package 2
- Service package 1 + Service package 2

Scenario 2: Decreasing demand for subscriptions over simulation horizon.

I. Product-oriented economic model
- Service package 1
- Service package 2
- Service package 1 + Service package 2

II. Use-oriented economic model
- Service package 1
- Service package 2
- Service package 1 + Service package 2

III. Result-oriented economic model
- Service package 1
- Service package 2
- Service package 1 + Service package 2

Figure 46. Illustrative example of an experience plan to be simulated on the sPS^{2}Simulator.

Once the simulations were run following the experience plan, the simulation outputs of each simulation were extracted and compiled. These outputs were aggregated into a second dashboard. This dashboard

aims to compare the economic added value of each alternative delivery network. An example of this second dashboard, derived from applying the sPS^{2}Risk framework in a case study concerning elm.leblanc, is presented in Chapter 7 (Section 7.3.2).

In addition to enabling the operationalisation of the 'scenario analysis' activity, the sPS^{2}Simulator also supports the execution of the sensitivity analysis activity. Based on the insights obtained from the abovementioned dashboard, a second experience plan is elaborated. As explained in section 5.6, this plan aims to assess the impact of a set of input parameters on the KPIs and metrics calculated by the sPS^{2}Simulator through a one-at-a-time (OAT) sensitivity analysis. The new set of simulation runs is executed on the sPS^{2}Simulator. Then, the simulation outcomes are extracted, compelled, and plotted in a tornado chart. The utilization of the sPS^{2}Simulator in the task D4.3 is summarized in Figure 47.

The dashboard comparing the alternative value delivery scenarios and the tornado chart are used to support decision-makers in obtaining evidence about the viability of the Smart PSS offering. Consequently, this IT tool is intended to serve as a mechanism for the design team to control the economic risks associated with deploying a service-based offering. It is worth mentioning that the sPS^{2}Simulator is a first mock-up of a financial performance evaluation IT tool that could be implemented in the elm.leblanc's operations. Therefore, limitations and improvement opportunities are present in the final version of the sPS^{2}Simulator developed.
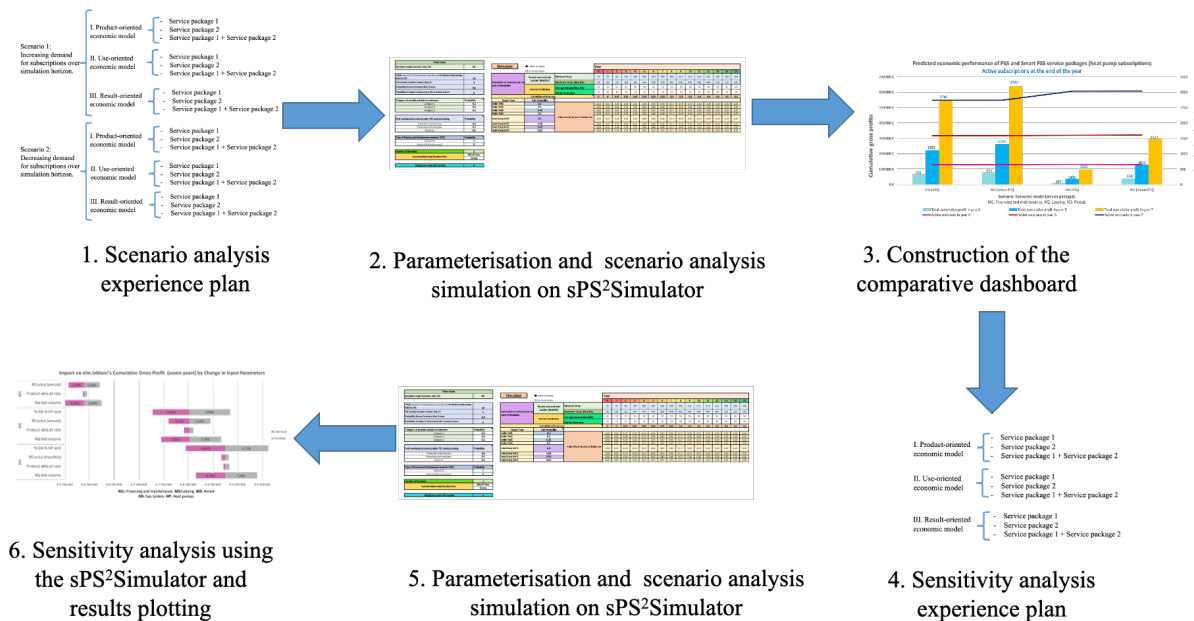
Figure 47. Employment of the sPS^{2}Simulator in the 'Economic analysis and uncertainty assessment' task.

Conclusions

This chapter presents the toolset that enables the application of the proposal presented in chapter 5 in a real design setting of the residential heating business. The toolset mentioned above comprises classical tools used in the design and project management fields and two computer-based tools tailored to design service-oriented offerings. These IT tools allow designers to model the value architecture components and simulate the economic performance of both PSS and Smart PSS offerings.

The first customized computer-based tool is called sPS²Modeller. This tool is a modelling software program that has two main functionalities. First, it creates graphical representations of the components associated with the service-oriented offering value proposition and value delivery network(s). Second, it stores and allows sharing of the pieces of information collected throughout the Smart PSS design proposal application. The resulting graphical representations and the information collected during the application of the proposal's 'iterative design loop' (Figure 18) are used as a basis to establish the economic models associated with the alternative service delivery networks. Subsequently, the financial performance of these service delivery scenarios is simulated on a modelling platform.

A simulation platform called sPS²Simulator was built to enable the execution of this economic performance included in the proposal's 'iterative validation loop' (Figure 18). This second IT tool estimates a set of economic performance indicators for the key actors involved in each value delivery scenario. These two tailored computer-based tools (sPS²Modeller and sPS²Simulator) are aimed to provide managers and professionals with actionable insights concerning the innovation risks linked to the potential Smart PSS commercialization. These insights are expected to lead the design to make well-informed decisions. Thus, these IT tools enhance the capabilities of the decision-making process during the early design phase. In the following chapter, the utilization of the toolset presented in this chapter within the application of the proposal introduced in Chapter 5 is documented through a case study.

Chapter 7. Application of the sPS²Risk framework to design Smart PSS offerings in the heating business

Introduction

This chapter illustrates the applicability of the design framework and the associated toolset (presented respectively in Chapters 5 and 6) in a case study called 'heating-appliance-as-a service.' The focal firm's professionals validated the proposal and the customized IT tools across multiple workshops before being employed in the case study. The firm involved in this case study, elm.leblanc, a subsidiary of the Bosch Group, has traditionally sold pure products and maintenance contracts separately. The products are sold through business-to-business channels (B2B), while the service contracts are sold directly by the firm to the customer (Figure 48).
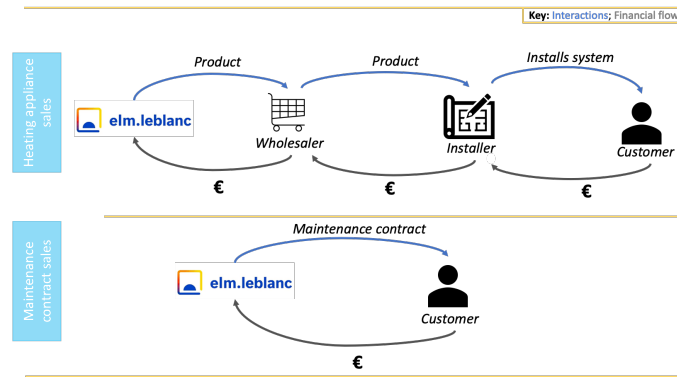
Figure 48: Elm.leblanc's current sales channels in the individual residential heating market.

Presently, the residential heating industry's business trend is moving towards selling subscription-based and all-inclusive solutions enabled by digital technologies. Hence, elm.leblanc has started exploring the possibility of implementing these digital and service-oriented offerings, inspired by the initiatives in this field of the Bosch Thermotechnology subsidiaries in Germany and the Netherlands. Since the design of these types of offerings is a new activity for elm.leblanc, the company collaborated in this thesis to acquire the capabilities to carry out this design process and manage the risks associated with the novelty of these value offerings in its portfolio. The latter aspect is critical, as the risk of not generating enough economic profit from commercializing these offerings may compromise the firm's financial health.

This chapter aims to validate the sPS²Risk framework. Consequently, the remainder of this chapter is structured according to the two main design loops reminded in Figure 49. First, the overview of the case study is detailed in section 7.1. Next, the application of the proposal's iterative design loop, corresponding to the first three methodological blocks and the utilization of sPS²Modeller, are reported in section 7.2. The following section describes the application of the iterative validation loop corresponding to the methodological blocks D and E. Here, the utilization of the sPS²Simulator in implementing the methodological block D is reported. Lastly, the proposal's effectiveness, applicability, and added value in the design of digital and service-oriented offerings for heating systems are discussed.
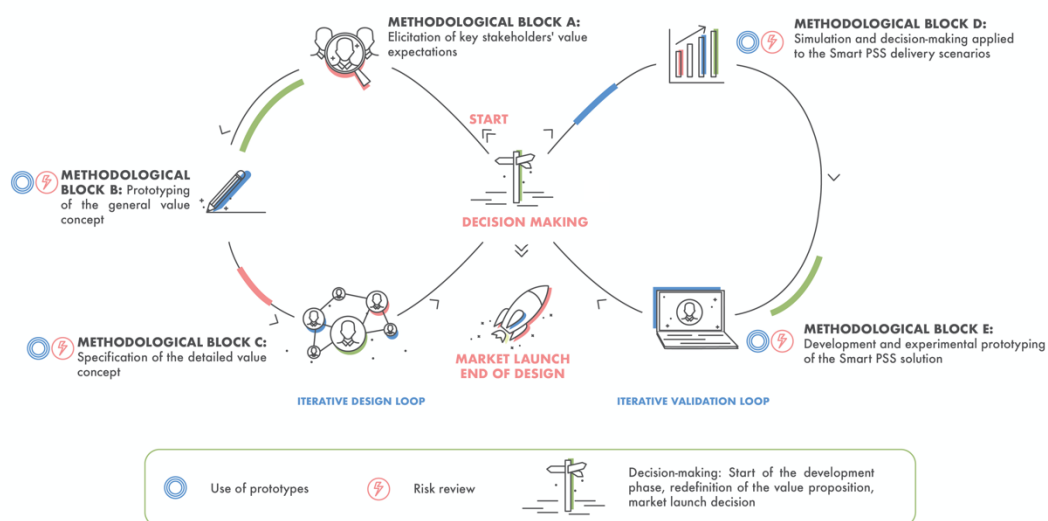
Figure 49: sPS²Risk framework's structure.

7.1 Overview of the case study

As presented in section 2.4, 'Heat-as-a-Service' (HaaS) has emerged as a promising business trend to cope with the challenges posed by the energy transition. In turn, this business trend is affected by the influence on customer needs of the growing number of connected home appliances and their associated digital services. Therefore, connected heating appliances and digital services are expected to be included in the 'HaaS' offerings. Given the current regulations in the French market, the variant of the 'HaaS' offering known as 'heating-appliance-as-a-service' was selected as a case study. This variant implies that the customer pays a 'service provider' a recurring fee for the use of the heating appliance instead of the traditional upfront payment for the heating system and its installation. Connected heating appliances are likely to be included in this offering.

A connected heating appliance can be controlled remotely, unlike a conventional one (i.e., the user can control their heating and hot water from their phone or other devices). This functionality facilitates the delivery of digital services, such as the remote monitoring of the appliance aimed to predict malfunctions. When the sensor installed in the appliance identifies the probability of a breakdown, it alerts the service engineer or installer about the incident and the spare part that needs to be replaced. The customer is also informed about the breakdown, and the time it will take for the service engineer to travel to their home and repair the heating appliance. Consequently, Smart PSS offerings in the residential heating business include a bundle of connected appliances and physical and digital services to satisfy customers' needs.

Elm.leblanc has previous experience in the design of digital services. In 2006, the firm launched the remote diagnostic service for gas boilers called 'Thermibox.' This service was commercialized as a pure service in the form of a maintenance contract between elm.leblanc's after-sales department and individual housing residents. Despite the offering's innovativeness at that time and the various benefits reported, 'Thermibox' did not meet its financial targets. As mentioned in section 2.4.1, three reasons were pointed out as causes of these financial results (Herve,2016). First, the service offer was addressed to the wrong stakeholder, as customers did not perceive the added value of paying for this additional service (desirability risk). In addition, two feasibility risks played a role in this outcome: Thermibox's technical system support was aging and not scalable to the newest product references, and the after-sales service operators found the system difficult to use. Considering the ongoing business trends in the residential heating industry (Section 2.4) and the lessons learned with the Thermibox offering, elm.leblanc decided to delve into the possibility of offering a packaged solution including the remote diagnostic service.

In the variant of the 'HaaS' offering addressed in this case study, two risks usually borne by the customer are transferred to the actors of the service delivery network (Figure 6). First, the risk concerning that the client defaults on their payments that cover the credit to finance the heating system purchase and its installation. Second, the risks associated with the appliance's technical performance, as traditionally, the

customer bears the costs associated with the preventive maintenance interventions and the repair when a breakdown occurs. As heating appliance manufacturers do not traditionally have all the competencies and resources to deliver these packaged solutions, they need to establish partnerships with external actors. Among these actors, we can mention IT-related companies, installers, after-sale service firms, finance providers, and reverse logistic partners. In this value network perspective, the notion of win-win outcomes becomes decisive in the design process. In the following section, the application of the iterative design loop of the sPS²Risk framework for designing a 'heating-appliance-as-a-service' including the remote diagnostic service is demonstrated.

7.2 Application of sPS²Risk framework: the iterative design loop

The residential heating industry is characterized by fierce competition and the influence of important actors such as energy suppliers who offer heating installation services and maintenance contracts. A strategic contextualization was carried out to determine the focal firm's position against novel initiatives that are likely to reshape the heating business. Among these initiatives, we find the housing retrofit projects to attain net-zero energy homes and government programs for heating system replacement "at 1€". The government's efforts to decarbonize heating undoubtedly impact the focal firm's strategy, as bans on new oil- and gas-powered heat from new homes have come into effect. However, the customer affordability of high-energy-efficient heating systems and their associated operational costs may hinder these efforts.

The internal strategic analysis highlighted the brand's reputation in the market, the products' reliability, the technicians' know-how, and the existing partnership with certified installers. Owing to the French market size and the heating replacement rates, the customer segment corresponding to heating system replacement in individual private homes was targeted for the design of service-oriented offerings. The map of the stakeholders involved in this segment was modeled in the 'ecosystem view' of sPS²Modeller (Figure 50). Based on this representation, two key stakeholders were designated besides elm.leblanc: the private homeowner interested in replacing their heating system and the installers. The latter are key actors in the product-based value chain as manufacturers rely on installers to market their products to private homeowners. Then, a service-oriented business model should include them, as elm.leblanc does not have direct distribution channels to customers.
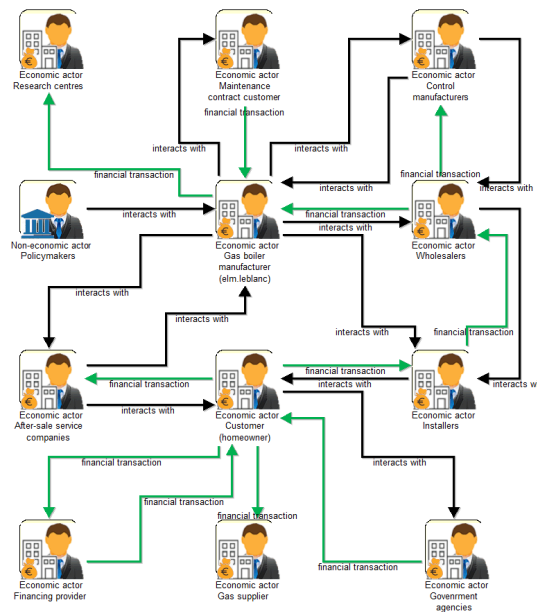
Figure 50. Conceptual model created on the sPS²Modeller representing elm.leblanc's business ecosystem.

7.2.1 Application of the methodological block A: Elicitation of stakeholders' value expectations

Task A1.1: Understanding key stakeholders' needs.

In order to obtain insights into these abovementioned stakeholders, the reports elaborated by an external firm were used to support this methodological block's application. This consulting company in the heating business field conducted two online surveys to collect information aimed at defining customer jobs, gain points, and pain points of private homeowners and installers. The first survey asked 200 private homeowners in France about their households' characteristics (e.g., income, age) and different aspects of their home heating (e.g., thermal comfort in winter, cost, concerns with their heating system's operation, perception about the value added by the remote diagnostic service). This survey's results led to the definition of three customer personas, describing the profiles of the clients who might be interested in an alternative offer to the traditional purchase of heating appliances and those who might not be.

This same consulting firm reached 300 heating appliance installers based in the United Kingdom to collect their needs. The installers' business models in the United Kingdom and France are undifferentiated. For this reason, the results of this survey were considered for this design process. The installers were inquired about the channels they use to gain new customers, their perception of customers' needs, and the tasks related to their work. Customer personas were created for the installers based on the interviews' results.

> As the results of the interviews and the customer persona definitions are part of the intellectual property of this consulting company, further details cannot be disclosed in this thesis.

Task A1.2: Observing key stakeholders.

Based on the findings from the interviews, two customer journey maps addressing each key stakeholder's perspective were represented as part of the thesis work with the assistance of the abovementioned consulting firm. From the customer's point of view, the 'journeys' involved in the heating appliance replacement and the heating appliance breakdown and repair were mapped. From the installer's perspective, their experiences associated with ordering the heating appliance from the wholesaler and its installation process at the customer's home were represented. Subsequently, improvement opportunities in the 'journeys' of these stakeholders were identified.

Task A1.3: Defining a point of view.

All the information collected and analysed in these previous tasks must be re-expressed with one very synthetic question, called in the Design Thinking approach, the 'How might we' (HMW) question. This question constitutes a so-called 'point of view,' which synthesizes the expression of the needs. This point of view is later used to lead the brainstorming session described in the following subsection (task B1). For our case study, this HMW question and 'point of view' was defined as:

> *'How might we contribute to facilitating customer access to energy-efficient heating appliances while not affecting the installers' business model and ensuring recurrent revenues for elm.leblanc?'.*

7.2.2 Application of the methodological block B: Prototyping of general value concept

Once the design team identifies and synthetizes the key stakeholders' needs, the next question this team addresses is how to meet these needs through a service-oriented and digital enabled value proposition. To do so, the tasks described in section 5. 4 are applied.

Task B2.1: Ideation.

Based on the insights gathered in the previous methodological session and a synthesis of the service-based offerings existing in the European market, a brainstorming session was prepared following the specifications in Chapter 5. This session was aimed to devise service-based value propositions for the private homeowner customer segment and was held in October 2020. A heterogeneous group of professionals from multiple departments of the heating appliance manufacturer participated in this session. This group of professionals that we call the 'design team' was made up of professionals from product development, IT, after-sales service, and product release management departments.

The resulting brainstormed value proposition consisted of two types of subscriptions, summarized in Figure 51. The client pays a recurring fee for the heating appliance's availability in these subscriptions. During the brainstorming session, the design team members agreed to explore the possibility of offering these subscriptions under three economic models available in the market: finance and maintenance, leasing, and rental. These economic models are further detailed in section 7.3.1.1.

Subscription #1	Subscription #2
• Heating appliance installation. • Availability of the heating appliance during the subscription period. • Routine maintenance and repairs.	• Content of the subscription #1. • Remote diagnostic service. • Energy consumption monitoring.
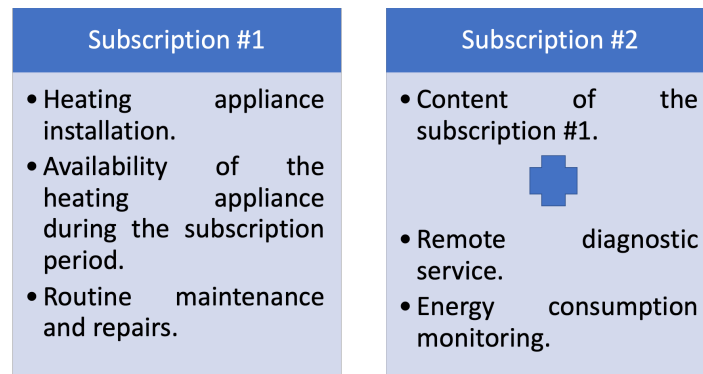
Figure 51. Recap of the brainstormed value proposition.

Task B2.2: Conceptual prototyping of the value proposition.

The outputs of this brainstorming session were firstly represented and recorded in the 'product' and 'service' modelling views of sPS²Modeller. The service catalogue included in the value propositions was broken down into the solution's lifecycle stages and the stakeholders concerned (Figure 52). The heating appliances included in the devised value propositions are gas boilers and heat pumps, and the thermostat is their corresponding periphery product.

To sum up, this service catalogue's scope concerns: (i) the financing solution, (ii) the classical range of the heating appliance installation service, (iii) the services currently comprised in the after-sale contracts commercialized by elm.leblanc (routine maintenance and breakdown insurance), (iv) the remote diagnostic service and (v) the activities associated with the termination of the subscription. The customer segment targeted by the brainstormed value propositions was represented on the 'demand' modelling view. The key interview findings and the customer journey maps resulting from applying the methodological block A were recorded on open documents. Links to these open documents were stored on the modelling object called 'customer class'. This modelling object is available on the 'demand' modelling view (Figure 53).

The number of potential clients was quantified again with the assistance of the abovementioned consulting firm in the heating business. Among the factors treated for this market size estimation, we can mention the number of occupied households in France (excluding the rental housing market), the annual replacement rate (considering the heating appliance sales and the installed base), and the service-based subscription appeal reported in the interviews mentioned in the previous methodological block. This size estimation was linked to the customer personas potentially interested in these kinds of all-inclusive solutions.
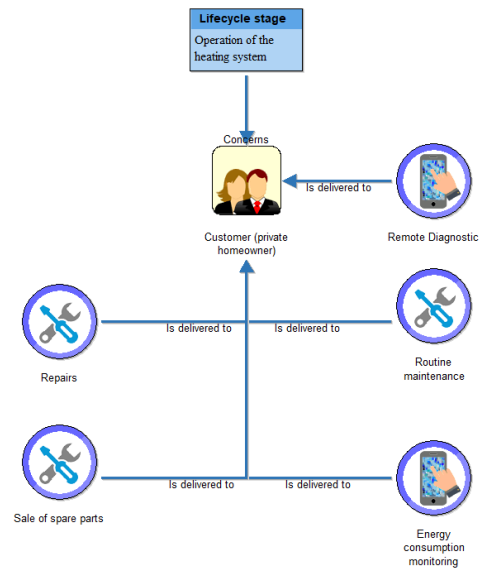
Figure 52. Snapshot of the the 'service' modelling view on sPS²Modeller for the heating system's operation lifecycle stage.

Figure 53. Access to the key interview findings and customer journey maps on the sPS²Modeller.

Task B2.3: Configuring the value offering.

The value propositions brainstormed in task B1 were modelled as value offerings in the view 'offer' of sPS²Modeller (Figure 54). These value propositions were proposed to be sold as product- and use-oriented subscriptions. In the first subscription type, called 'financing and maintenance,' the client buys the heating appliance through credit. The classical maintenance contract (including the mandatory annual maintenance routine and the repairs' travel and labour costs) is bundled in this subscription.

Additionally, two use-oriented subscriptions were modelled, in which the customer pays for the heating appliance's availability either by a leasing subscription (the customer has the option to buy the appliance if they decide to cancel the subscription) or a rental subscription. In turn, in each subscription, two service packages (PSS and Smart PSS) are proposed to the customer. The Smart PSS content includes the service offered in the PSS service package and the remote diagnostic service (Figure 54). A third additional service, radiator bleeding, currently offered by elm.leblanc, can be eventually added to these service packages.

Table 17. Main characteristics of the economic models considered in the case study.

Aspect	Financing and maintenance (M1)	Leasing (M2)	Rental (M3)
Economic model type	Product-oriented	Use-oriented	Use-oriented
Average subscription period in the existing offerings	Five years	From eight to twelve years	Minimum two years; after this period, the subscription duration is indefinite. This means that the client can cancel the subscription anytime.
What happens when the customer cancels the subscription?	The client must reimburse the remaining amount of the credit, and the maintenance contract is suspended.	The client can either buy the appliance for its residual value or have it uninstalled. The only valid options to end the subscription are the death of the client or the sale of the client's home.	The appliance is uninstalled with no option to buy it.
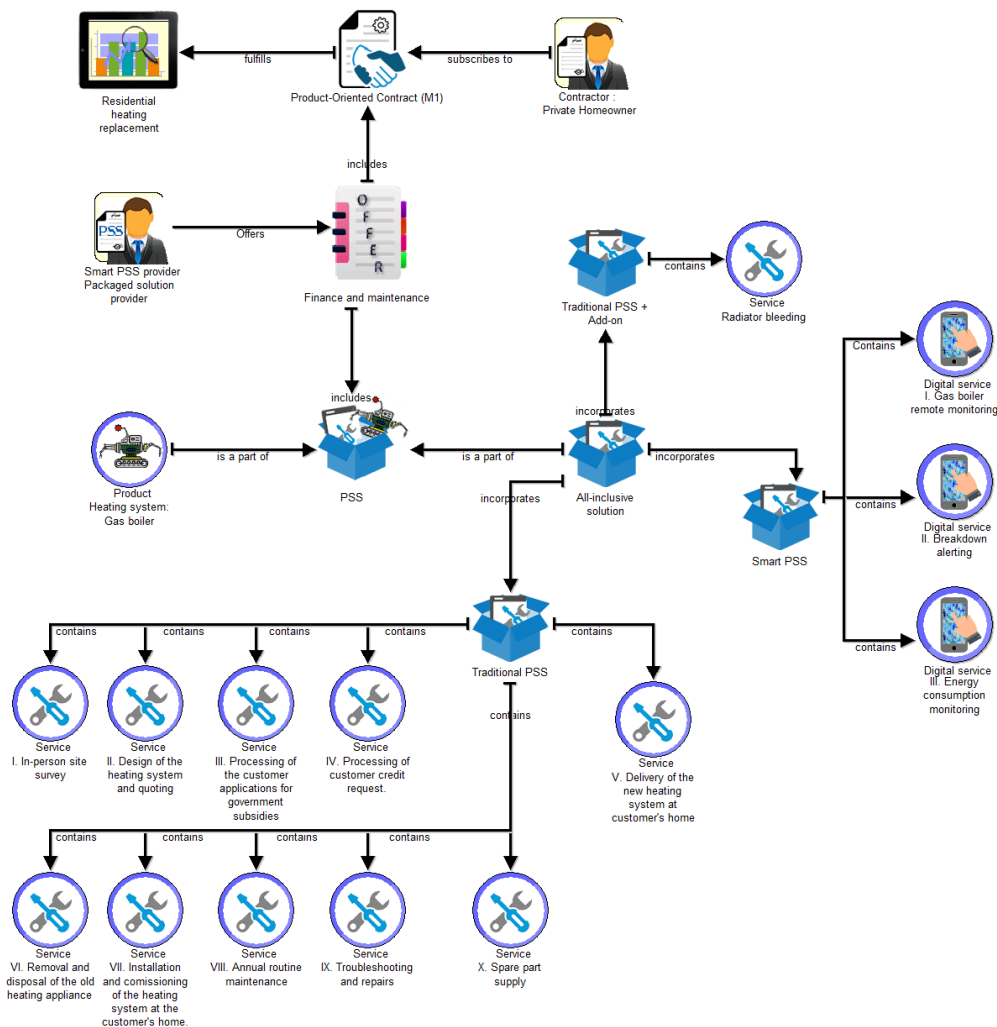
Figure 54. Snapshot of the 'offer' modelling view on sPS²Modeller for the 'Financing and maintenance' (M1) subscription.

Task B2.4: Validation.

The final conceptual models that captured the insights obtained in this methodological block were confronted with professionals from the after-sales and research and development departments. This confrontation was carried out through a group discussion that led to the question of whether the remote monitoring value-added monetary value for the private homeowner in the product-oriented economic model. As a result, it was decided to study the possibility of offering the Smart PSS service package with no additional charge for the customer. This alternative is addressed in section 7.3.2.

Task B2.5: Risk review.

Several innovation risks were identified during the modelling procedure in this methodological block and discussed in the risk review. The most critical risks are summarized in Table 18. This risk register was made accessible to the design team through a link to an open document stored on the modelling object called "offer", specifically in the tab "risk." This modelling object is available on the modelling view of the same name (See section 6.1.5).

Table 18. Innovation risks identified during the application of the methodological block B

Innovation risk category	Risk description
Desirability	- Not enough potential customers are interested in ownerless heating solutions leading to poor sales of service-based subscriptions. - Private homeowners do not perceive the value of subscribing to the remote monitoring service, then this digital service's revenue does not cover the operational costs and investments. - A vast number of potential customers might not be interested in the product-oriented subscription for two reasons: (i) their household income allows them to cover the upfront cost of the heating appliance replacement, and (ii) they are not willing to bear the credit and insurance costs. These reasons may lead to low market acceptability of the value proposition. - Based on their low household incomes, an important share of potential customers is currently entitled to receive generous subsidies from the government for their appliance replacement, making the product- and use-oriented subscriptions unappealing for these households. - Potential customers are not interested in long-term subscriptions, as the permanency rates at the same dwelling may greatly vary across different European countries (i.e., people tend to change homes in periods shorter than the leasing subscription period), making the leasing option (use-oriented) unattractive in the market - The digital service might not be allowed by regulations to be advertised as a solution for energy consumption reduction, as one of the main customer pain points identified was the high cost of energy bills. The lack of orientation toward lower energy bills decreases the digital service's appeal to the customer.
Feasibility	- The use-oriented subscriptions are not legally attainable as the understanding of French regulations is that the heating system is included in the property. Therefore, uninstalling a heating system at the end of the subscription might not be done easily.

Two main control measures were decided to address these risks. First, additional interviews with a new sample of private homeowners may be necessary to obtain more solid evidence of the offering's desirability and the motivations to sign a subscription-based contract. These interviews are aimed to dig deeper regarding customers' viewpoints on use-oriented subscriptions compared to the traditional

upfront payment and their financing preferences to buy new heating appliances. Second, the potential market size must be segmented according to households' incomes, as it was acknowledged that government subsidy schemes play a major role in selecting a purchasing alternative to replace a heating system.

Despite the risks identified and described in Table 18, it was agreed to continue with the execution of the tasks of the next methodological block. This decision was mostly based on the information processed in the methodological block A, where factors such as the entire French market size, the annual heating appliance replacement rates, and the pain points that were identified from the interviews with private homeowners.

7.2.3 Application of the methodological block C: Specification of the detailed value concept

Once the Smart PSS value proposition is outlined, the following question that the design team addresses is how this value proposition will be delivered to the customer. This question is handled in this methodological block by applying the tasks described in the section 5.5.

Task C3.1: Design of the value network.

This task addresses the configuration of the alternative value networks that can deliver the value propositions prototyped in tasks B2 and B3. Five modelling views of the sPS^{2}Modeller are employed to support this task ('activity', 'organisation', 'performance', 'scenario', and 'value network') following the guidelines described for this task in section 5.5, specifically in Figure 25. The importance of this task lies in the identification of the network feasibility to deliver the Smart PSS value proposition. This task was applied considering all the economic models (i.e., finance and maintenance, leasing, and rental) proposed to deliver the service-based value proposition that was brainstormed in the methodological block B.

What are the activities required to deliver the value proposition?

The activities necessary to carry out the services included in the value offerings modelled in the 'offer' view of sPS^{2}Modeller were represented in the 'activity' view. Among the macro-activities that are new to elm.leblanc's core business and are necessary to build the value network that will deliver the all-inclusive subscription, we can mention: (i) financing solutions for the purchase of appliances, (ii) heating appliance installation, (iii) processing of data collected from installed appliances, (iv) uninstallation and disposal of heating appliances, and (v) product refurbishing. The focal firm may decide to carry out some of these activities in-house and hence, invest in developing new capabilities or assign these activities to external actors.

What external actors have the necessary competences and resources to carry out these activities?

To illustrate the application of our proposal, we will assume that an external key commercial partner takes over some of these activities. This hypothetical situation was based on the case of Bosch Germany, in which this heating appliance manufacturer established partnerships with multiple actors to deliver the

product-, use-, and result-oriented subscriptions[1]. In this case, the external actors that provide the offering to the customer are a bank, a contractor, and an energy company. We will refer to the hypothetical actor interacting with the customer as the service provider. This actor oversees customer acquisition, customer request processing, and billing activities.

The ' organization ' modelling view represented the identification of actors that possess the resources and capabilities to accomplish the macro-activities, modelled previously (See Appendix I.1). In this view, the technical and financial risks usually taken on by the client were graphically transferred to elm.leblanc and the service provider, respectively. In the "financing and maintenance" subscription, it was decided to consider that the financial risk was transferred from the service provider to an external insurance company. In this same offer, the technical risk is borne by elm.leblanc through the manufacturer warranty and the maintenance subscription's scope that includes the labour and travel fees of the repairs. In the "leasing" and "rental" subscriptions, elm.leblanc also bears this risk during the agreed warranty period. Then this technical risk is assumed by the service provider as the appliance owner. In these use-oriented subscriptions, the service provider also bears the financial risk as it purchases the heating system.

From this 'organisation' modelling, the uncertainty about the required actors to upgrade and refurbish the heating appliances that would eventually be uninstalled when the customer ends the subscription was pointed out. This situation emerges in the case of use-oriented subscriptions. Wholesalers were considered as the hypothetical actors that could play this role related to the end-of-subscription activities.

What performance indicators define the actors' value expectations from the service-oriented value network?

Since the scope of this thesis concerned the profitability analysis of the alternative Smart PSS value networks, the selected performance indicators and metrics exclusively covered the economic dimension. These value expectations were expressed through the following indicators: sales revenue, gross profits, and total costs. The operating margin was selected as a profitability indicator. This choice was made considering that Bosch's financial targets for these kinds of recurrent revenue projects are measured in terms of the operating margin.

What service delivery network configurations are possible? What roles can the actors play in these alternative networks?

The roles of the actors previously identified are modelled for each potential scenario, using the 'scenario' modelling view. In this case study, a scenario combines a subscription sold through a specific economic model (i.e., financing and maintenance, leasing, and rental) and a service package (PSS or Smart PSS).

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[1] https://www.bosch-thermotechnology.com/de/de/wohngebaeude/wissen/presse/pressemappe-neuheiten-2020/heizungsfinanzierung/

Elm.leblanc's roles in all the scenarios are twofold. First, to manufacture and distribute the heating appliances to the wholesalers. Second, the provision of the maintenance service (including the remote monitoring option) and the supply of spare parts to the customers that subscribe to the all-inclusive subscription. Other tangible and intangible deliverables pinpointed through the 'scenario' visualization are described in Appendix I.1.

What interactions (financial transactions, data flows, product, and service flows) take place in these alternative value networks?

The transactions implemented to exchange these deliverables in the alternative scenarios were represented in the 'value network' view of sPS^{2}Modeller. The model shown in Figure 55 depicts an example of the value network configurations associated with delivering the value offering represented in Figure 54 and is based on the assumptions resulting from the preceding steps. These assumptions are described in Appendix III.2. This value network representation allows to attribute costs and revenues to the actors involved and document their responsibilities in the value network. In this model, the principal financial transactions are:

(i) The traditional product-based value chain is maintained. This implies that elm.leblanc sells the appliances to the wholesalers. Then, the installers buy the appliances for the all-inclusive subscriptions at the wholesalers. These appliances are installed in the customers' homes. Similarly, the control manufacturer sells thermostats and connectivity hardware to wholesalers, and successively these products are bought by the installer from the wholesaler.

(ii) The service provider purchases the heating system from the installer and pays them for their installation service via a one-time payment.

(iii) The financing for purchasing the heating systems from the installers differs in each economic model. In M1, the appliance purchase and installation are financed by a credit provider and the government subventions, whereas in M2 and M3, the appliances are financed by the service provider.

(iv) The customer is billed monthly by the service provider for the all-inclusive subscription.

(v) The maintenance and digital service payments vary depending on the economic model. (See Appendix I.2).

From this to-be model, it can be inferred that the service provider is this value network's orchestrator. This actor is the only firm that interacts with the customer. Hence, the service provider owns the customer channel (e.g., through a digital platform) and has bargaining power over the products included in the packaged solution subscription, the installers' margins on the heating systems, and the after-sale service firms' margins on the maintenance operations. Moreover, this service provider must ensure the quality of the installation carried out by the external installer and customer claim handling. From the model, it can also be deduced that elm.leblanc adds value to this network through the product's

reliability, the warranty period, brand awareness, the service engineers' expertise, and the rapid delivery lead time of spare parts.

The added value offered to the customer can be summarized as follows: (i) the affordability of high-energy efficient appliances for clients who cannot bear high upfront costs, (ii) the product's technical performance, and the quality of the maintenance service that ought to be reflected on energy bill reduction, (iii) and consequently a reduction on the environmental impact, (iv) the peace of mind having a heating system operating smoothly, (v) and lastly, the convenience of having a single provider for all the aspects concerning the heating system.

Task C3.2: Validation and verification.

Through a new collaborative validation meeting, the value network configurations represented in the conceptual models were confronted with professionals from the after-sales and research and development departments. The value networks' feasibility was validated considering that elm.leblanc currently has a strong partnership with a network of installers across France. These installers are currently trained and certified by elm.leblanc, and this collaboration can be exploited to convince them to integrate the delivery network. Installers may increase their sales turnover if they propose an all-inclusive subscription to customers that cannot afford the upfront payment. The feasibility of establishing partnerships with the remaining required business partners was also considered to be feasible as currently elm.leblanc interacts with those actors for other purposes.
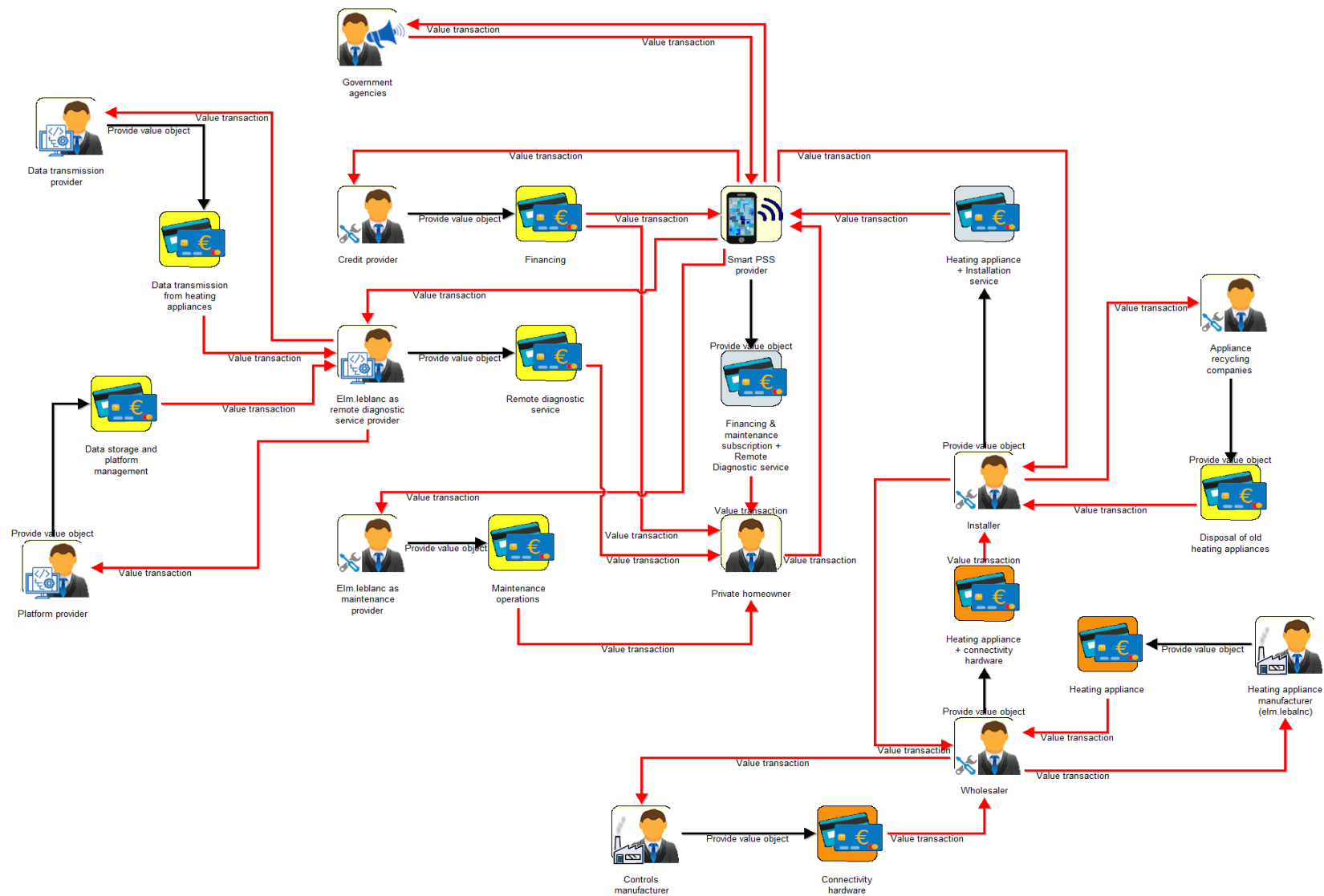
Figure 55. Snapshot of the 'value network' modelling view on sPS^{2}Modeller for the 'Financing and maintenance' (M1) subscription including the Smart PSS service pack

Task C3.3: Risk review.

The incremental and iterative creation of the models enabled the identification of several innovation risks, as described in Table 19. These innovation risks were added to the risk register created in the methodological block B. As a reminder, this risk register is available on the 'offer' modelling object of the sPS²Modeller's view of the same name.

Table 19. Innovation risks identified during the application of the methodological block C.

Innovation risk category	Risk description
Feasibility	- As an important group of installers may not be willing to negotiate their margins with external parties, the required number of installers willing to engage in the value network is insufficient to cover subscription sales. Therefore, the demand cannot be met. - There are not enough trained heat pump installers; therefore, the demand for packaged solutions using this technology or the waiting times for the installation cannot be met[2]. - IT-related actors are difficult to convince to integrate the value network as they do not perceive the value they can obtain from their participation. Most of this value may be challenging to express in monetary terms. Then, the digital service cannot be deployed. - The digital service cannot be compatible with the product range. Therefore, its scalability may be limited. - The agreement on customer data ownership may cause frictions with other value network actors and impede data monetization.

7.3 Application of sPS²Risk Framework: the iterative validation loop

As a reminder, in the offer view, two economic models (product-and use-oriented) were considered. The product-oriented economic model incorporates a single subscription called 'financing and maintenance,' whereas two use-oriented subscriptions were defined: leasing and rental. Each one of these subscriptions contains alternative service packages. Two service packages were included in the economic performance simulation presented in section 7.2.2, 'PSS' and 'Smart PSS.' The Smart PSS package consists of the remote diagnostic service as an add-on to the content of the PSS package.

This validation loop consists of two methodological blocks. In these methodological blocks, the economic performance of the alternative value networks to deliver the service-based value proposition is assessed. Then, based on the financial performance results, a prototype of the Smart PSS solution is developed to be tested with a group of potential customers.

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[2]https://energycentral.com/system/files/ece/nodes/520696/whitepaper_ashp_cost_reduction_potential_october_2021_1.pdf

7.3.1 Application of the methodological block D: Simulation and decision-making applied to the Smart PSS delivery scenarios

This section describes the application of the four tasks included in this methodological block (Figure 56). In this task, the sPS²Simulator is developed and deployed to implement the tasks concerning the economic performance assessment of the alternative value networks drafted in the previous methodological block.
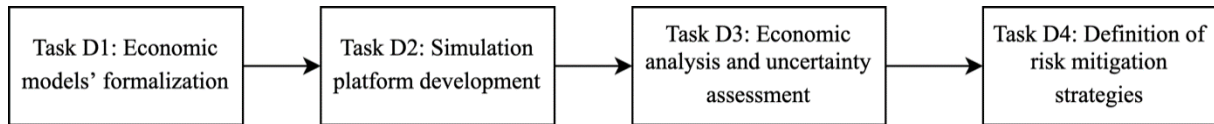
Figure 56. Internal structure of the methodological block D.

7.3.1.1 Task D4.1: Formalization of the economic models to be simulated.

The agreed objectives for this methodological block were: (i) to determine whether including the Smart PSS package into the 'heating appliance-as-a-service' subscription adds value for elm.leblanc, and (ii) to predict the profitability of the economic models' implementation from a multi-actor perspective. These objectives aim to deliver actionable insights to elm.leblanc's decision-makers concerning the viability of implementing a 'heating-appliance-as-a-service' bundled with the remote diagnostic service. As a reminder, one product-oriented and two use-oriented economic models were considered for this methodological block: financing and maintenance (M1), leasing (M2), and rental (M3).

The descriptions of each economic model can be found in Table 20. Two service packages were included in the subscriptions: PSS and Smart PSS (Figure 57). The value network actors considered for this economic assessment were elm.leblanc in the roles of maintenance provider and appliance manufacturer, the installer network, the service provider, and the customer.
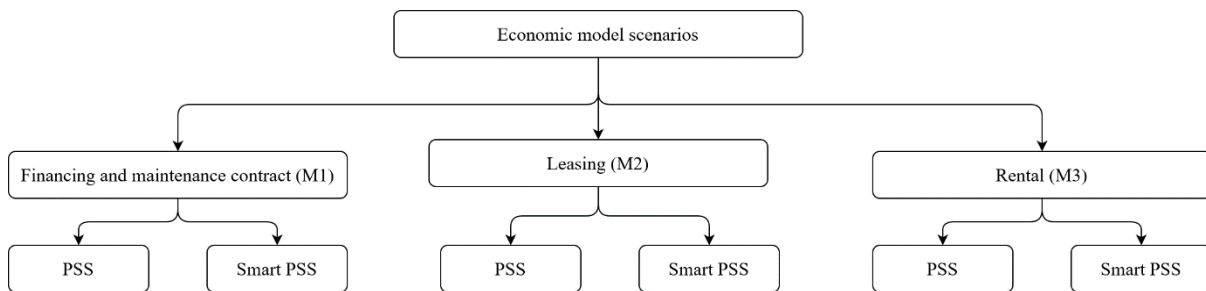
Figure 57. Economic model scenarios considered in the economic performance simulation.

Table 20. Main characteristics of the economic model scenarios considered in the economic performance assessment.

Aspect	Financing and maintenance (M1)	Leasing (M2)	Rental (M3)
Heating appliance's ownership	The customer owns the heating appliance and pays for the credit through the monthly fee reimbursed to the service provider.	The service provider owns the heating appliance and leases it to the customer for a specified period, after which ownership is transferred to the customer.	The service provider owns the appliance and rents it to the customer for an indefinite period, ideally until it needs to be replaced.
Responsibility for maintenance and repair costs	- This subscription includes the mandatory routine maintenance and the labour and travel costs for repairs. - Spare parts are charged extra to the client. The warranty applies to the components of the boiler defined by the manufacturer.	The service provider retains ownership of the device and must cover all maintenance and repair costs, including spare parts (unless the customer is the cause of the problem).	

The conceptual models elaborated on the 'offer', 'scenario', and 'value network' modelling views were used as input to transform these economic models' descriptions (Table 20) into mathematical equations. These equations reflect each value delivery scenario's financial and physical flows. These physical flows trigger monetary exchanges amongst the value network actors, represented in these mathematical equations that we call profit equations. For instance, among the physical flows, we can mention the number of heating appliances sold thanks to the subscriptions and the maintenance interventions.

The formulation of these equations led to listing a set of input parameters needed for the simulation runs. The information necessary to set the threshold value of the input parameters, and to calculate the costs used as parameters in the equations, was collected with the aid of Bosch employees and external experts. These costs were estimated by applying the Activity-Based Costing technique as presented in Farsi et al. (2020).

Regarding the Smart PSS package, the direct captured value considered for the remote diagnostic service varies based on the economic model. For M1, an additional monthly fee to the PSS service package paid by the private homeowner was considered. In contrast, for M2 and M3, the assumption was that the service provider paid an annual fee in advance for each installed heating appliance (Figure 58).
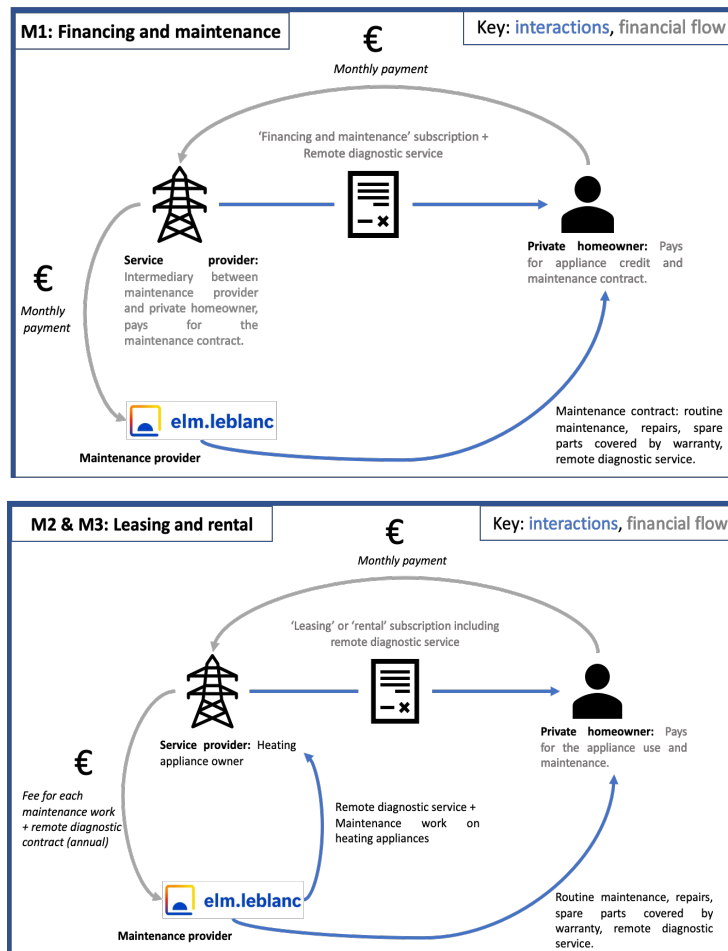
Figure 58. Financial transactions for the maintenance operations in the economic models.

In order to compare the economic value of Smart PSS subscriptions with PSS ones, the indirect captured value considered was the reduction of service engineers' visits and the appliance repair time. The assumptions made to estimate this indirect captured value were based on information available in technical reports of the heating business about the remote diagnostic service's monetary benefit. Lastly, the chosen key performance indicators and metrics to be monitored from the economic assessment results were the sales revenues, gross profits, operating margins for key actors, and the number of active subscriptions. In addition, other metrics concerning the maintenance service are considered, such as the number of repairs and routine maintenance operations required to fulfil the subscription's scope. These metrics can eventually be utilized to estimate the human resources needed to deliver the services included in the subscription.

The output of this task is the profit equations associated with each alternative value network drafted in the methodological block C. These equations express the costs and revenues incurred for each key actor during the whole lifecycle of the subscription.

7.3.1.2 Task D4.2: Development of the simulation platform.

This computer-based tool was called sPS²Simulator and is employed to implement the task D3. The development process of this tool is detailed in section 6.2. The simulation platform is customized to the case study taking as a starting point the profit equations formulated in the task D2. The building blocks developed during this task and mentioned in section 6.2 of this manuscript were adapted to each value delivery scenario considered in this economic assessment (Figure 57). Thus, the final version of the simulation platform was ready to simulate the key economic performance indicators associated with each value delivery scenario.

7.3.1.3 Task D4.3: Economic analysis and uncertainty assessment.

Once the sPS²Simulator was operational, the task D3 was carried out. This task represents the core of the economic performance assessment. To facilitate the implementation of this task, we broke it down into four stages (Figure 59). The application of these stages is detailed in the following subsections. In the first stage, the objectives of the economic analysis are outlined (Table 21). Then, the following three stages address these objectives successively by employing the method known as scenario analysis. The sPS²Simulator is used in these three stages to carry out the scenario analysis. In the last stage, we conduct a sensitivity analysis with the support of the sPS²Simulator. This sensitivity analysis aims to identify the most impacting input parameters on the cumulative gross profits for each economic model.
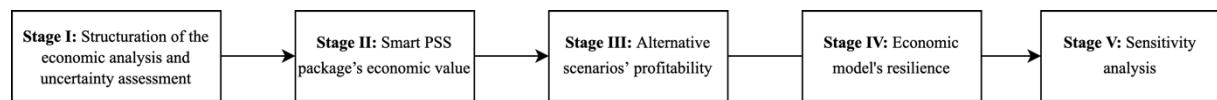
Figure 59. Stages of the task E3.

7.3.1.3.1 Task D4.3-Stage I: Structuration of the economic analysis and uncertainty assessment.

The economic analysis employs the scenario analysis method to assess the economic models' profitability and resilience. An experiment plan describing this scenario analysis and the simulation runs required was defined. In this plan, three input parameter configurations were established and named 'pessimist', 'realistic', and 'optimist' (Appendix II.1). In addition, five input parameters have been changed simultaneously in each configuration: the volume of new subscriptions sold every month during the simulation horizon (using a uniform probability distribution), the markups on products and services, the cancellation rate, the renewal subscription rate, and the products' default rate over their lifetime. Each simulation run represents a scenario (combination of an economic model and a service package, either PSS or Smart PSS) under an input parameter configuration. Each run was replicated 30 times. The simulation horizon was fixed to seven years in all the simulation runs.

A comparative dashboard was conceived to display the simulation outputs. This dashboard aims to compare the profitability of the alternative value delivery scenarios from a multi-actor perspective. In this economic analysis, four key value network actors were included:

(i)   elm.leblanc as heating appliance manufacturer and maintenance provider

(ii)   the installer network

(iii)   the service provider

(iv)   the private homeowner.

The goals of this economic analysis and the conceived dashboard are described in the following stages of this task. The assumptions considered in the alternative value delivery scenarios are detailed in Appendix I.2. In all the simulation runs, the inputs related to the demand for 'heating-appliance-as-a-service' subscriptions were based on estimates for the French market, elaborated by a consulting firm. For the sake of simplicity, the economic analysis dashboard using the simulation outputs was structured as shown in Table 21.

Table 21. Description of the economic analysis' goals and stages.

Stage	Actor's role perspective	Key managerial questions addressed	Stage's goal	Scenarios simulated	Input configurations
II	Maintenance provider	1. Does commercializing a Smart PSS service package generate increased monetary value compared to the option of solely commercializing a PSS service package? 2. For each considered economic model, is it convenient to commercialize a Smart PSS offering from the profitability perspective?	Assess the economic value of delivering the Smart PSS service package.	1. <u>Gas boiler subscriptions:</u> PSS vs. Smart PSS service packages. 2. <u>Heat pump subscriptions:</u> PSS vs. Smart PSS service packages.	'Realistic configuration'
III	- Maintenance provider - Heating appliance manufacturer	1. What economic model(s) generate the highest profits for elm.leblanc? 2. What scenarios are the most convenient for elm.leblanc, from the profit-generation point of view?	Assess the profitability of the alternative scenarios.	1. <u>Gas boiler subscriptions:</u> PSS vs. Smart PSS service packages. 2. <u>Heat pump subscriptions:</u> PSS vs. Smart PSS service packages.	'Realistic configuration'
IV	- Maintenance provider - Heating appliance manufacturer - Installer network - Service provider - Private homeowner	1. What scenarios are the most convenient for all the key actors from the profit generation perspective? 2. Do these scenarios maintain the expected profitability when the values of a set of key input parameters change simultaneously?	Test the resilience of the economic models in different input parameter configurations.	1. <u>PSS service packages:</u> Gas boiler and heat pump subscriptions combined. 2. <u>Smart PSS packages:</u> Gas boiler and heat pump subscriptions combined.	'Pessimist', 'realistic' and 'optimist' configurations

7.3.1.3.2 *Task D4.3-Stage II: Smart PSS package's economic value.*

This stage aims to quantify the impact of adding the Smart PSS service package to the 'heating-appliance-as-a-service' subscription. The mean of the cumulative profits was plotted in the dashboard aimed to compare the alternative scenarios, including the three economic models named M1, M2, and M3 (Figures 60 and 61).

In this stage, elm.leblanc's perspective as the maintenance provider that delivers the remote diagnostic service is addressed. Simulations were run considering either solely gas boiler subscriptions or solely heat pump subscriptions. The direct value captured related to the Smart PSS offering that we included in this simulation was the revenue from the billing of the remote diagnostic service. As for the indirect value captured, we considered the savings in the maintenance operations enabled by the remote diagnostic service.

This economic assessment did not include additional revenue streams such as data monetization. Despite the importance of this revenue stream in the value capture process of Smart PSS offerings (Opresnik et al., 2015), the sale of data collected from the heating appliances was not considered in the financial transactions drafted in the application of the methodological block C. This choice was made considering that the sale of data extracted from appliances installed at customers' homes remains a sensitive topic (Holgado et al., 2020). For this reason and in line with practitioners' point of view, we did not include such potential captured value in this economic analysis.

The inputs considered in this stage:

These simulations were run with a set of input parameters that we labelled 'realistic'. The other two input parameter configurations established for the economic analysis were labelled 'pessimistic' and 'optimistic'. However, only the 'realistic' input configuration was included in this stage.

In these input parameter configurations, the value of five input parameters varies. These input parameters are the monthly market volume associated with the subscriptions, the products' default rate according to their age, the cancellation rate of the subscriptions, the subscription renewal rate, and the actors' markups on products and services.

Main findings:

Figures 60 and 61 show the cumulative gross profits derived from the maintenance service on the left vertical axis and the number of active subscriptions on the right vertical axis.
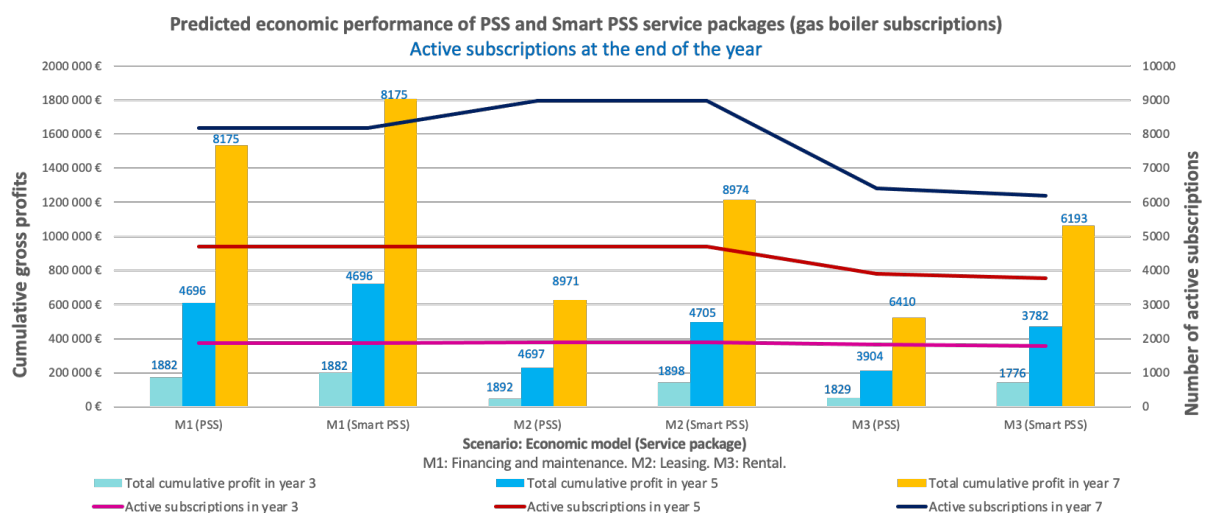
Figure 60. Cumulative gross profits derived from the maintenance operations for gas boiler subscriptions.
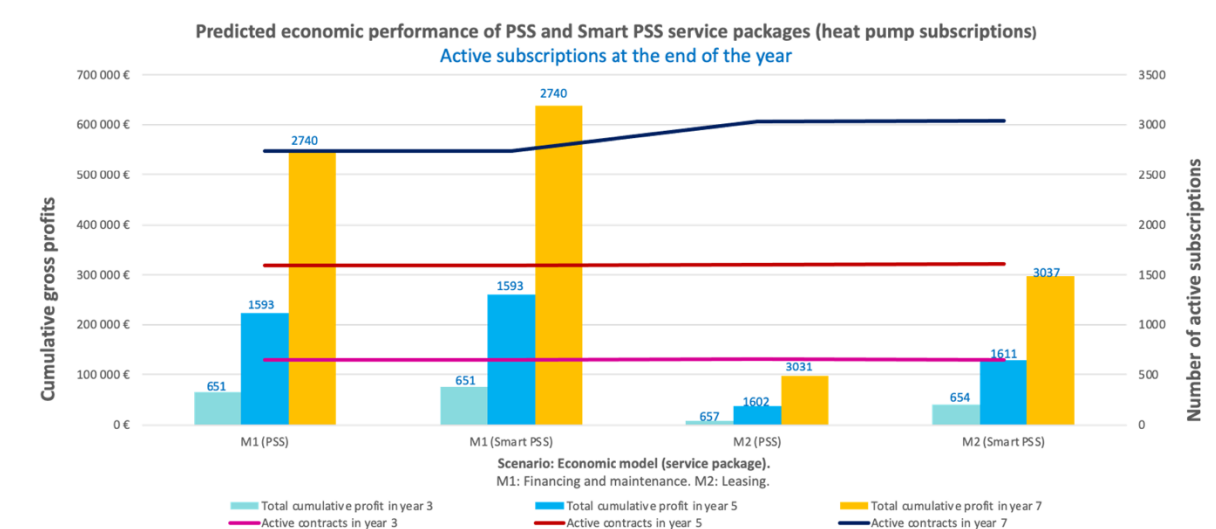
Figure 61. Cumulative gross profits derived from the maintenance operations for heat pump subscriptions.

Table 22 displays the cumulative gross profit per active subscription at different times of the simulation horizon for both gas boiler and heat pump subscriptions.

Table 22. Scenarios' cumulative profit per active subscription.

Scenario	Gas boiler- cumulative profit per active subscription			Heat pump- cumulative profit per active subscription		
	Year 3	Year 5	Year 7	Year 3	Year 5	Year 7
M1 (PSS)	91 €	130 €	188 €	100 €	140 €	199 €
M1 (Smart PSS)	106 €	154 €	221 €	116 €	164 €	233 €
M2 (PSS)	26 €	48 €	70 €	13 €	24 €	32 €
M2 (Smart PSS)	76 €	106 €	135 €	62 €	81 €	98 €
M3 (PSS)	28 €	54 €	82 €	Scenario not considered		
M3 (Smart PSS)	80 €	125 €	172 €			

Following the simulation results, the highest profits seem to be obtained with the financing and maintenance economic model (M1) for both service packages. The dominance of this product-oriented economic model can be explained by the assumptions considered to formalize the monetary exchanges related to the maintenance operations. For this economic model, a monthly recurring revenue to cover the maintenance contract fees (included in the monthly subscription price) was modelled in the simulation. In contrast, for the use-oriented economic models (leasing and rental), the simulation model considers an hourly rate fee for repairs and routine maintenance and an annual recurring fee for the Smart PSS package.

In other words, in addition to the recurring fee for the remote diagnostic service, the maintenance provider's revenue depends on the number of routine maintenances and repairs carried out. This assumption was included considering that this payment structure is common in B2B contexts, where a third party owns the heating appliance used by the end-user (e.g., social housing landlords). Spare part sales are included in this maintenance provider's perspective. If elm.leblanc's warranty does not cover

the spare parts, these parts are charged to the private homeowner in M1 scenarios and the service provider in M2 and M3 scenarios.

Figures 60 and 61 also indicate that the financing and maintenance subscription combined with the Smart PSS service package generates the greatest benefits among all the simulated scenarios. However, for the case of the economic model M1 (Financing and maintenance), the assumptions that explain this result seem challenging to attain in the real-world market. In the scenario involving this economic model, we assumed that all customers taking the subscription were willing to add the Smart PSS package and pay an additional monthly fee of 6€.

In that regard, elm.leblanc's previous experience with the commercialization of the Thermibox service (see section 2.4) revealed that a significant number of private homeowners were unwilling to pay an extra fee for this remote diagnostic service. Given the above, two options to include this digital service in the subscription emerged from the exchanges with elm.leblanc's design team:

- o The first option includes the Smart PSS package in all the subscriptions with no additional fee for the customer. This option is currently offered in the French market by a service provider that provides the all-inclusive solution addressed in this case study under the economic model M1.

- o The second option considers leaving the private homeowner the choice to add the Smart PSS package for an extra fee lower than 6€ per month. The French service provider mentioned in the first option offered this possibility to the customer until the end of the year 2021.

First option regarding the economic model M1: including the remote diagnostic service for free in all the subscriptions

Regarding the first option, we aim to predict the impact on the cumulative profits of not charging an additional fee to the customer. To do this, we simulate the expected profitability while varying the monthly cost per customer to deliver the remote diagnostic service. As a reminder, in the simulations, this individual monthly cost was fixed to 5€. This cost estimate covers the digital platform operation, the labour cost of the staff dedicated to tracking the data sent from the heating appliances, and data transmission fees (Delta EE 2021). Accordingly, a new set of simulation runs was carried out in which the cumulative profits were calculated with different values of the individual monthly delivery cost for the remote diagnostic (Figure 62). In these simulation runs, gas boilers and heat pumps are considered. The other input parameters, including the volume of new subscriptions, remain identical in these simulation runs.
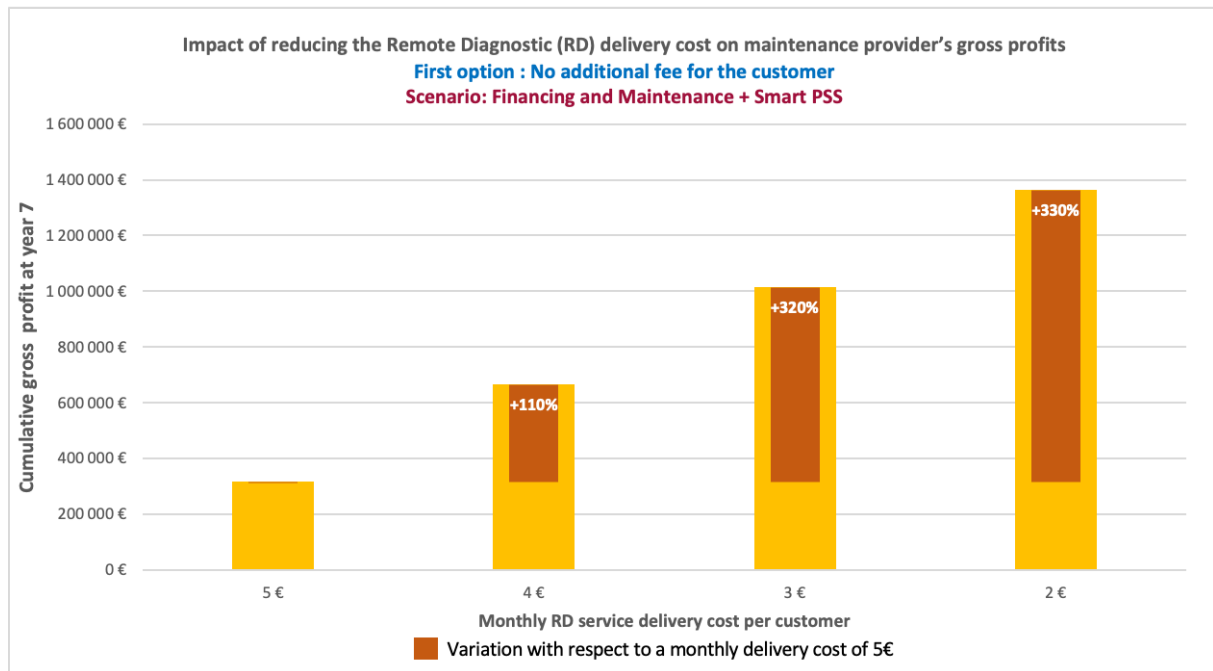
Figure 62. Simulation results of the option considering the free delivery for the customer of the remote diagnostic service in all subscriptions (economic model M1).

The results displayed in Figure 62 are summarized in Table 23. Three main findings can be highlighted:

i. The subscription that includes the free remote diagnostic service for the customer does not generate an operating loss if the monthly delivery cost remains 5€ per customer.

ii. For every euro reduced in the monthly digital service delivery cost per customer, the benefits increase by approximately 350,000 €.

iii. If the individual delivery cost is lowered to at least 3€ per month, the cumulative gross profit will exceed one million euros. In other words, the cumulative gross profit could be higher than one million euros if the individual remote diagnostic delivery cost can be lowered to at least 3€ per month.

Table 23. Cumulative profit per active subscription considering free remote diagnostic service for all subscriptions.

	Monthly remote diagnostic delivery cost per customer			
	5 €	4 €	3 €	2 €
Maintenance provider's cumulative profit at year 7 (gas boiler and heat pumps subscriptions combined)	316 607 €	665 471 €	1 014 336 €	1 363 200 €
Cumulative profit per active subscription	31 €	66 €	101 €	135 €

The abovementioned cumulative gross profits could be enhanced if the savings in the maintenance operations are higher than those considered in our simulation. Based on the report by Delta EE (2019c), we assumed that thanks to the remote diagnostic service, the number of first repair visits by the service

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engineers was reduced by 7%. As for the number of second repair visits to repair a heating appliance, we considered that this number was reduced by 20%.

From Table 22, it can be observed that in year 7, for a PSS service package, the cumulative gross profit per subscription for gas boilers is 188€, and for heat pumps is 199€. In contrast, in Table 23, it can be noted that even by lowering the monthly delivery cost per customer to 2€, the cumulative profit per active subscription does not exceed 135€. This value is significantly lower than the same metric for PSS packages, either for heat pumps or gas boilers.

Second option regarding the economic model M1: Leaving the customer the choice to add the Smart PSS service package for an extra monthly fee lower than 6 €

A new set of simulation runs was carried out to evaluate this option. These subscriptions include both gas boilers and heat pumps like in the option previously presented. The percentage of Smart PSS subscriptions relative to total 'finance and maintenance' subscriptions and the value of the monthly Smart PSS fee for the customer were varied. The value of the monthly Smart PSS delivery cost per customer remained fixed. Figure 63 shows the results of these simulation runs.
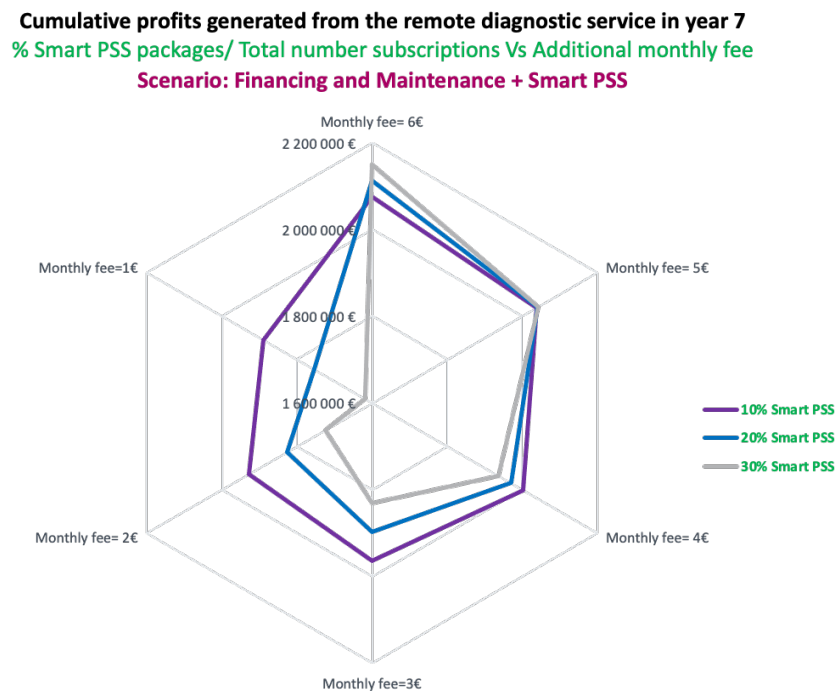
Figure 63. Simulation results of the option of leaving the customer to add the Smart PSS package for an additional fee.

As expected, if the additional monthly fee is lower than the monthly delivery cost, the increase in the number of Smart PSS subscriptions reduces the cumulative profit. From Figure 63, considering a delivery cost of 5€, it can be observed that the highest gross profits are obtained when 30% of private homeowners pay a fee of 6€. This situation implies that the maintenance provider makes a monthly margin equal to 1€ per Smart PSS subscription.

The assumptions about the indirect captured value in the form of savings in the repair operations are the same as in the previous option assessed. Therefore, in order to not limit the profits derived from the maintenance operations, the private homeowner should be charged a fee equal to or more than the monthly and individual delivery cost. Nonetheless, private homeowners' desirability of this digital service remains uncertain, especially when it comes to new heating appliances owned by the client.

To sum up, for the economic model M1, we consider two alternative options: commercializing either a PSS service package or a Smart PSS service package with no additional charge to the customer. Based on the two abovementioned findings, the option of commercializing the PSS service package under the economic model M1 seems to generate a higher cumulative gross profit per active subscription from the perspective of elm.leblanc as the maintenance provider.

Conclusions of the stage II of the task D4.3

For the use-oriented economic models (leasing and rental), referenced as M2 and M3, the inclusion of Smart PSS packages generates higher profits than in PSS scenarios. This pattern can be explained by the assumption that the service provider, as the heating appliance owner, pays an annual subscription for the remote diagnostic service and buys the connectivity hardware. In these economic models, the Smart PSS bill is paid in advance.

For the product-oriented model (financing and maintenance), referenced as M1, it was stressed above that the option of delivering a PSS service package appears to generate a higher cumulative gross profit per subscription.

Table 24. Summary of the main findings derived from the stage II of the task D3.

Economic model	Financing and maintenance (M1)	Leasing (M2)	Rental (M3)
Service package with the highest estimated profits	PSS	Smart PSS	
Revenue sources from the service package	-Classical maintenance contract that covers routine maintenance and repairs (travel and labour). This contract is paid every month. - Sale of spare parts if not covered by the warranty.	- Remote diagnostic contract. This contract is paid on an annual basis. - Routine maintenance is paid at an hourly rate. - Repairs are paid at an hourly rate. - Sale of spare parts if not covered by the warranty	
Cumulative profit per subscription	Gas boilers= 188€ Heat pumps= 199€	Gas boilers= 135€ Heat pumps= 98€	Gas boilers= 172€

7.3.1.3.3 Task D3-Stage III: Alternative scenarios' profitability.

Aim of this stage and input parameter configuration considered:

In this stage, we continue considering the perspective of elm.leblanc. Given that elm.leblanc plays two roles in the drafted value networks resulting from the methodological block C, in this stage, we add the profits obtained from the sale of the heating appliances included in the subscriptions to the profits derived from the maintenance operations (addressed in the previous stage). Simulations including either solely gas boiler subscriptions or solely heat pumps were included in this stage as carried out in the precedent stage (Figures 64 and 65). Moreover, like in the previous stage, the 'realistic' input parameter configuration is utilized in the simulation runs.

Main findings:

As noted from Figures 64 and 65, profits from heat pump sales included in the subscriptions have a larger share in the total earnings than those of gas boilers. In these simulations, we assumed that the markup on the manufacturing and distribution costs was the same for both types of heating appliances. Moreover, it can be observed that for the use-oriented economic models, the inclusion of the Smart PSS package increases the share of the profits from the after-sales department on total profits. This share is increased by 10% for gas boilers and 5% for heat pump subscriptions. The lower percentage of the after-sales department's earnings for the economic model of leasing (M2) of heat pumps can be explained by the assumption of biannual routine maintenance. This routine maintenance is charged to the service provider based on an hourly rate instead of being included on a maintenance contract paid every month.
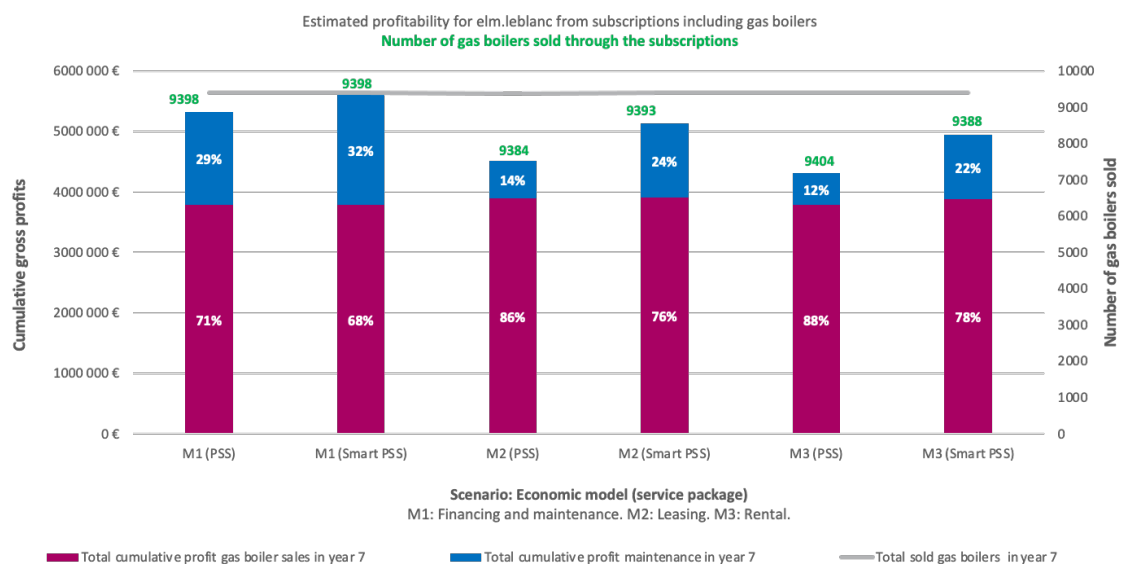
Figure 64. Cumulative gross profits derived from the maintenance operations and the sale of gas boilers included in the all-inclusive subscriptions.
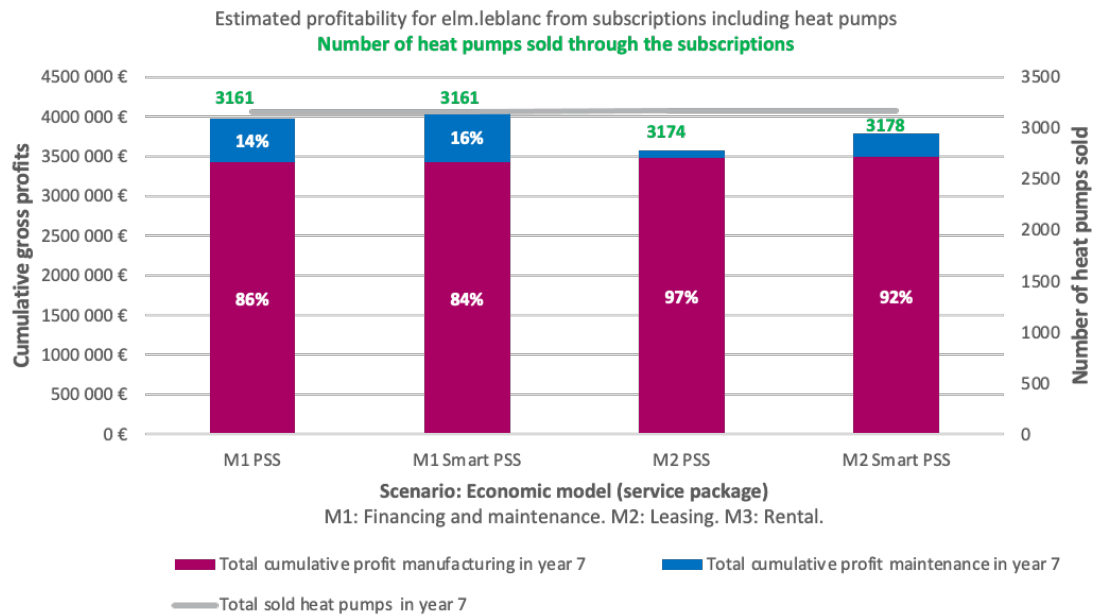
Figure 65. Cumulative gross profits derived from the maintenance operations and the sale of heat pumps included in the all-inclusive subscriptions

Conclusions of the stage III of the task D4.3

A summary of the main findings of this stage of the economic analysis is found in Table 25.

Table 25. Summary of the main findings derived from the second stage of the economic analysis.

	Gas boiler subscriptions	Heat pump subscriptions
Financing and maintenance (M1)	*Economic model that generates the highest profits. * Smart PSS package: unrealistic assumptions as explained in the stage I. New service delivery costs added. * PSS package: recurring monthly revenue from the classical maintenance contract included in the subscription increases the cumulative profits. * Spare part sales secured during the subscription period (five years).	*Economic model that generates the greatest profits. * Smart PSS package: unrealistic assumptions. New service delivery costs added. * PSS package: monthly recurring revenue as in gas boiler subscriptions. Biannual routine maintenance, which reduces the service delivery costs. * Spare part sales secured during the subscription period. * The share of heat pump sales profits is higher than that of gas boilers.
Leasing (M2)	* Smart PSS package generates the greatest profits for this economic model: recurring annual revenue from the remote diagnostic contract. * Annual routine maintenance and repairs are charged at an hourly rate; it generates lower cumulative profits.	* Smart PSS package generates the greatest profits for this economic model. * Recurring annual revenue from the remote diagnostic contract. * Biannual routine maintenance and repairs are charged at an hourly rate.

Rental (M3)	* Smart PSS package generates the greatest profits for this economic model: recurring annual revenue from the remote diagnostic contract. *Annual routine maintenance and repairs are charged at an hourly rate. *Flexibility in the duration of the subscription can reduce the profits from maintenance operations.	Heat pumps were not included in this economic model since no rental offerings of these appliances were found when this dissertation was drafted. Probably, this can be explained by the complexity involved in uninstalling a heat pump if the client cancels the subscription.

7.3.1.3.4   *Task D4.3-Stage IV: Economic model's resilience.*

Aim of this stage and inputs considered:

We predict the profits derived from the alternative scenarios while considering the perspective of the key value networks: elm.leblanc as the maintenance provider and heating appliance manufacturer, the installer network, the service provider, and the customer. In addition to the multi-actor perspective, we test the resilience of the scenarios to the simultaneous variation of a set of input parameters. To do so, we carry out the simulation runs using three different input parameter configurations that we called 'pessimistic', 'realistic', and 'optimistic' (See Appendix II.1). The value of the input parameters for each configuration was fixed considering expert opinion. As a reminder, the input parameters varied in these configurations are the monthly market volume associated with the subscriptions, the products' default rate according to their age, the cancellation rate of the subscriptions, the subscription renewal rate, and the actors' markups on products and services.

These simulation runs considered a combined demand for gas boiler and heat pump subscriptions. Each simulation run was replicated 30 times, and the cumulative gross profit was plotted for each key value network actor. The results of this resilience test for each key actor are presented in the following subsections.

Main findings:

   I.   Elm.leblanc's perspective as heating appliance manufacturer and maintenance provider:
Practitioners involved in the design team selected the operating margin as the primary decision criteria to determine whether an economic model meets the internal financial targets (see section 7.2.2). The operating margin is calculated by dividing the firm's income by its net sales (Investopedia, 2022). If a service-oriented economic model reaches an operating margin greater than or equal to 20%, it is considered to meet the financial target. Cumulative profits from maintenance operations and heating appliance sales included in the subscriptions are displayed in Figure 66.
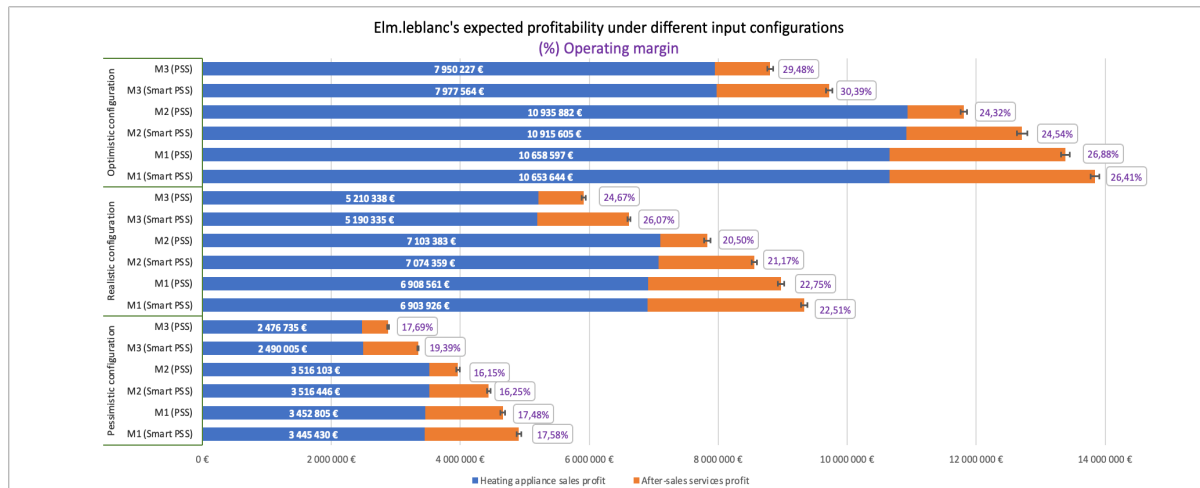
Figure 66. Simulation results of the resilience test from elm.leblanc's perspective (profits derived from the maintenance operations and heating appliance sales).

Figure 66 indicates that the operating margin target is not met under the pessimistic input parameter configuration. The main simulation outputs obtained for each economic model combined with the Smart PSS service package under the 'pessimistic' configuration are summarized in Table 26. These outputs imply that for each economic model, the threshold of values presented in Table 26 must be higher or lower depending on the metric, to meet the operating margin targets. For instance, the threshold of total heating appliances sold under subscriptions must be higher than those presented in Table 26. The number of repairs carried out, and the percentage of cancelled and non-renewed subscriptions must be lower than the values shown in Table 26.

Table 26. Main simulation outputs for each economic model combined with the Smart PSS package under the 'pessimistic configuration.'

Simulation output (cumulative output in year 7)	Financing and maintenance (M1)	Leasing (M2)	Rental (M3)
Heating appliances sold via subscriptions	8388 (Gas boilers and heat pumps combined)	8500 (Gas boilers and heat pumps combined)	8383 (Only gas boilers)
Active subscriptions	6711	7611	5013
Repairs carried out	4263	4535	3276
Percentage of cancelled and non-renewed subscriptions	20%	10%	40%

To sum up:

Among the additional findings depicted in this dashboard, we can mention that in all the configurations, the 'financing and maintenance' economic model (M1) generated the greatest gross profits. On the contrary, the 'rental' economic model (M3) generated the lowest gross profits in all the configurations. Interestingly, this economic model obtained the greatest operating margin in each configuration. This economic model's particularity is that it only considers the rental of gas boilers. Heat pump rentals were not found in the current 'heating-appliance-as-a-service' offerings in the European market when this case study was initiated. The unavailability of this specific offering may be explained due to the complexity involved in uninstalling a heat pump if the subscription is cancelled. Thus, the economic model M3 (rental) includes solely gas boilers in the financial assessment.

Additionally, in all the simulated scenarios, the Smart PSS package generated greater gross profits than the scenarios with no remote diagnostic service. Nonetheless, the scenario combining the economic model M1, and the Smart PSS package is based on the assumptions that were considered difficult to attain in the real-world market. These assumptions are described section 7.3.1.3.2 (the second stage of the task E3).

II.   *The installer network's perspective*

In all economic models, installers' profits depend on the market volume and the markups on the heating system and the installation service. First, and unsurprisingly, the more appliances sold under the subscriptions, the greater the revenues and, accordingly, the cumulative profits. Second, in the assumptions made in the application of the methodological block C, the markups on the appliances purchased by the installer at the wholesalers and on the installation service fee are negotiated with the service provider. Smart PSS packages generate an additional profit related to the margin on the connectivity hardware.

Figure 67 shows the simulation results from the installer network's perspective. The cumulative profits shown in this figure are considered for the entire installer network without distinguishing the type of heating appliance. However, we are aware that in the real world, an installer skilled at gas boiler installation may not necessarily have the competencies to install heat pumps.
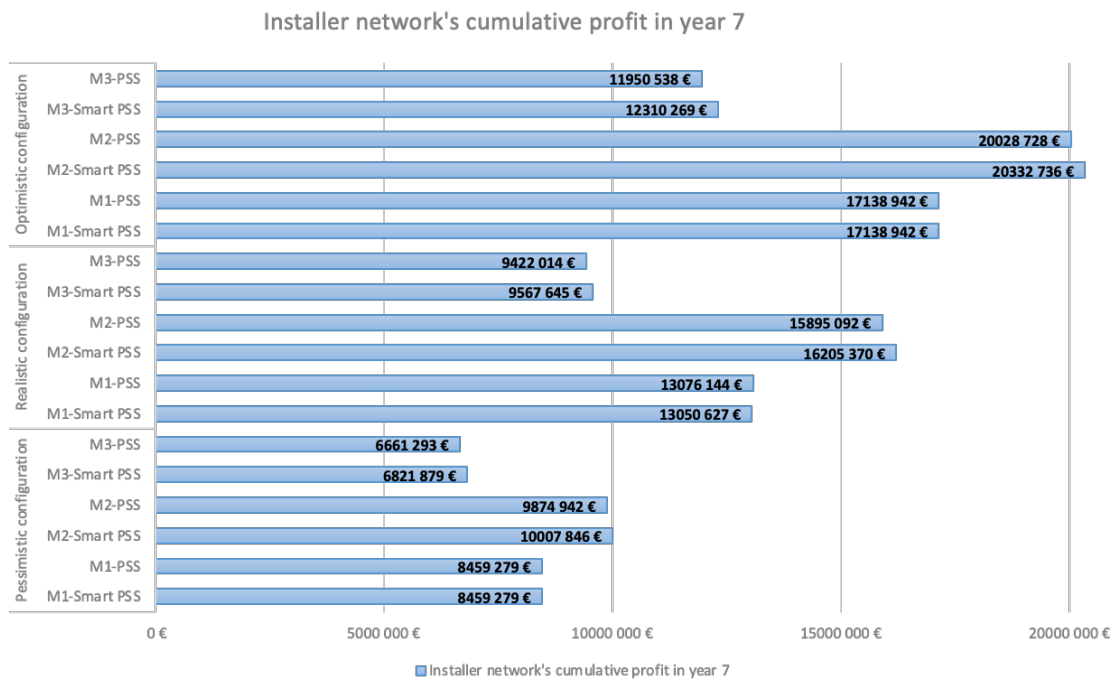
Figure 67. Simulation results of the resilience test from the installer network's perspective.

The simulation results indicate that the leasing economic model (M2) generated the greatest gross profits in all configurations.

Two circumstances can explain this output. First, this economic model incorporates an additional revenue stream for installers: the appliance uninstallation in case the client cancels the subscription and does not accept buying the appliance for its residual value. This revenue stream emerges in the rental model (M3) as well. In the simulation tool, uninstallations are triggered by the varied cancellation rates in all configurations. The variation of this input parameter was aimed to test its impact on the cumulative profits.

Second, this economic model includes heat pumps and gas boilers simultaneously. Since heat pumps have higher costs than gas boilers, when we apply the same markup for gas boiler installation, heat pump installation generates higher profits for the installers than gas boilers. The rental economic model (M3) only includes gas boilers which generate lower profits than heat pumps.

III. The service provider's perspective

The role and risks taken by the service provider vary in the various economic models (Table 27). Notably, in the use-oriented economic models (leasing and rental), the service provider owns and buys the heating appliances from the installers. These purchases are financed by internal funding. Heating appliances installed at customers' homes become the service provider's assets and are registered on its balance sheets. The depreciation of these assets is calculated monthly. The purchase of these appliances is paid back through the monthly subscription fee that includes an interest rate on the investment to make a profit for the service provider.

As the owner of a heating appliance fleet, the service provider seeks to reduce these appliances' running costs, specifically, the maintenance costs. The Smart PSS package appears to be a promising option for the service provider to keep running costs low if we consider the remote diagnostic service's monetary benefits (reduction in travel and labour costs of repairs. The simulation assumed that if the service provider subscribes to the Smart PSS package, the maintenance provider charges a preferential rate for the repairs.

Table 27. Service provider's roles in the alternative economic models.

	Financing and maintenance (M1)	Leasing (M2)	Rental (M3)
Role	Intermediary between the customer and: the credit provider, the maintenance provider, the government agencies that grant the subventions, and the installer.	*Heating appliance owner (appliance purchase funded by internal funding, subventions are not available for third parties, only for homeowners). * As the appliance owner, charges the customer for the use of the appliance.	
Risks transferred from the customer.	None: financial risk transferred to an insurance provider, and technical risk transferred to the maintenance provider (spare parts either covered by manufacturer's warranty or charged to the customer).	Financial and technical risks (spare parts included).	
Profit drivers	*One-time margin on the total heating appliance installation fee. This total installation cost is spread over the subscription period and charged to the client through the monthly subscription. * Recurring margin on the monthly subscription. This monthly billing covers the credit, the maintenance contract, and the credit insurance.	* Capital costs of heating appliances installation. * Internal rate of return of the appliances acquisition and installation. * Heating appliances' maintenance and depreciation costs. * Liability insurance costs. * Subscription price.	

The values of subscription prices used as inputs in the simulations were defined based on information available on various websites, especially concerning the upfront cost of heating appliance installations. These prices vary depending on the heating appliance type and the product reference. In the economic model 'financing and maintenance' (M1), these subscription prices are influenced by the subvention amount that private homeowners are entitled to claim based on their household income. For the leasing model (M2), these subscription prices considered the subscription period (it was fixed to eight years), the internal return rate of the heating appliance installation cost (4,9%), and the product lifetime. Lastly, for the rental model (M3), the subscription prices were fixed, considering the prices of an existing rental offering in the French market.
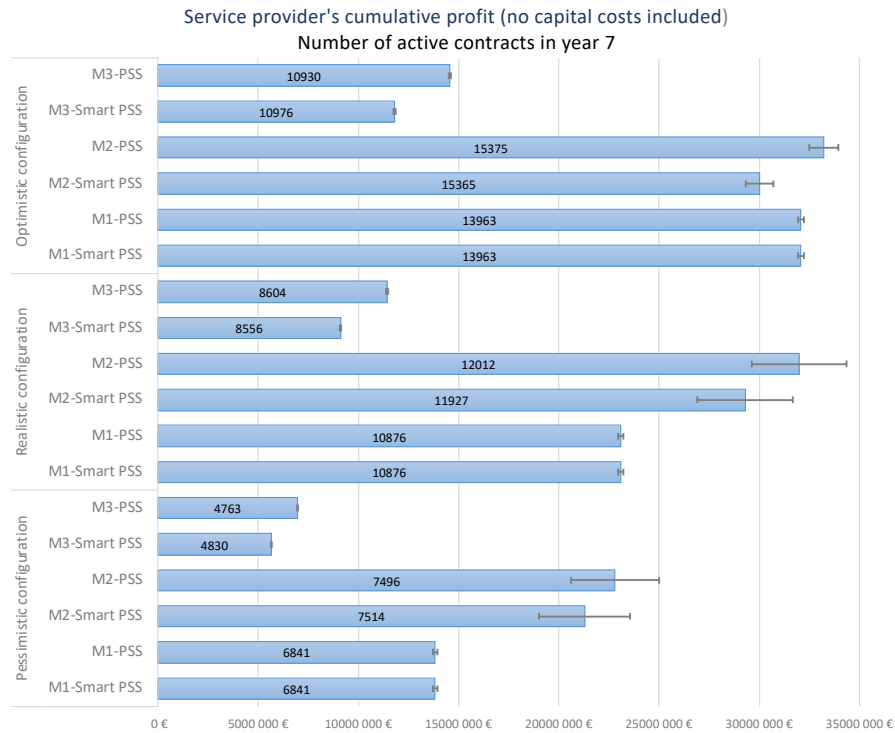
Figure 68. Simulation results of the resilience test from the service provider's perspective.

The simulation results are compiled in Figure 68. The main findings that we can highlight are:

o Figure 68 indicates that the highest profits for the service provider are obtained with the leasing *economic model (M2)*. However, in the use-oriented economic models (leasing and rental), capital costs associated with the heating appliance purchase and installation and the depreciation costs were not included for the sake of simplicity. If these costs are considered in these economic models, the cumulative gross profit will be significantly reduced.

o As can be seen from Figure 68, the rental *economic model (M3)* shows the lowest gross profits in the three configurations. This result can be explained by the subscription price values considered as inputs, which are the lowest of the three simulated economic models. As a reminder, this economic model only considers gas boiler subscriptions, which are cheaper than heat pump subscriptions.

o Concerning the *economic model (M1)*, we can highlight that the service provider makes a one-time margin on the total cost of the heating appliance installation (the installer's revenue), which is charged to the client and spread over the subscription period. Additionally, this economic model formalization included a recurring margin on the subscription price.

o Another significant finding concerns the *Smart PSS package*. The simulation results show that the Smart PSS package lowers the service provider's gross profits in the use-oriented economic models. In these scenarios combining Smart PSS packages and use-oriented models, the service provider as the heating appliance owner pays an annual fee for every installed appliance in advance. Therefore, Smart PSS packages generate additional expenses for the service provider. However, from the results shown in Figure 68, it can be noted that the expected savings in the

repairs (as described in task D3) do not outweigh the Smart PSS package costs for the service provider. In the product-oriented economic model (M1), this effect of the Smart PSS package on the service provider's gross profits is not seen. The reason for this outcome is that, in this 'financing and maintenance' economic model, the service provider is an intermediary between the private homeowner, who owns the appliance, and the maintenance provider. Hence, the service provider makes a margin on the Smart PSS subscription without taking any technical risks.

IV.   *The private homeowner's perspective*

Traditionally, when a private homeowner needs to replace their heating appliance, they must make an upfront payment. This upfront cost may be a barrier for homeowners installing energy-efficient heating appliances. Consequently, the 'heating-appliance-as-a-service' subscriptions are aimed to tackle this barrier by removing this upfront cost. The price of the heating appliance depends on several factors, such as the home's surface and the number of domestic hot water connections. This appliance price variability is also reflected in the price of heating-appliance-as-a-service subscriptions. Other than the heating appliance cost and the installation service, customers must bear the maintenance costs (mandatory routine maintenance, repairs, and spare parts). Another important element in the total cost of ownership of a heating appliance is the energy cost. Nonetheless, as the case study does not involve the pure 'Heat-as-a-Service' business model, this cost element was not included in the economic performance assessment.

Figure 69 plots the average individual cost per month of the subscription for the private homeowner in each of the simulated economic models. These values were extracted from the simulation platform. The scope of each subscription varies in each economic model. In the 'financing and maintenance' (M1) economic model, the subscription covers the heating appliance credit, the financing cost, and the maintenance contract (routine maintenance and labour and travel cost of repairs). In addition to these elements, the use-oriented economic models (M2 and M3) cover the spare parts needed in case of breakdown. Besides, the customer pays for the appliance usage rather than the heating appliance credit and the financing cost. A particularity of the rental economic model (M3) is the inclusion of a one-time installation cost for the customer. This entry fee was added based on the market's characteristics of existing rental offerings.

Average monthly cost for private homeowners for 'heating on subscription'
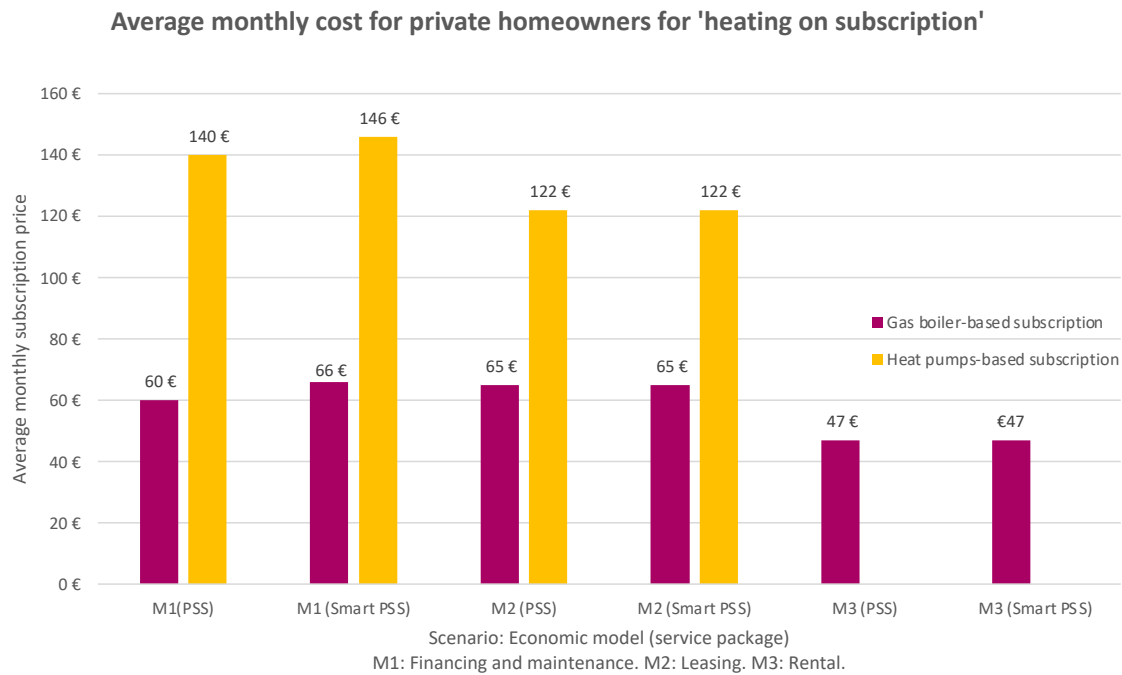
Figure 69. Average monthly cost for the customer in each scenario.

As noted in Figure 69, concerning gas boiler subscriptions:

○ The customer finds the lowest subscription price with a rental economic model (M3). However, these price values for this specific economic model were fixed based on existing rental subscription prices in the French market. The considered service provider offers this price, possibly for two reasons. First, they may have in-house installers, so there is no margin for the installers. Second, this service provider might buy appliances directly from a manufacturer, making additional savings on the total appliance installation cost.

○ The second cheapest average subscription price is found in the financing and maintenance economic model (M1) with no remote diagnostic service. This is a five year-subscription to pay off the credit for the appliance after subsidies have been deducted. In this subscription, if spare parts are needed and are uncovered by the manufacturer's warranty, the customer must pay for them.

○ In contrast, in the leasing model (M2), the customer does not have to pay for any expenses related to the maintenance. This subscription is more expensive compared to M1 because, under the current regulations, service providers cannot claim subsidies for themselves. Then, the entire cost of the gas boiler installation must be spread throughout the subscription period.

As for heat pump subscriptions:

○ The leasing subscription (M2) is cheaper than the financing and maintenance subscription (M1). Two factors can explain this difference in the subscription prices. First, heat pump installations are more expensive than those of gas boilers. Second, as the leasing subscription period is more extended (eight years), the heat pump acquisition and installation costs are spread longer.

Consequently, the fee to cover the heat pump usage is reduced. Additionally, the technical risks are transferred from the client to the service provider. In other words, the customer does not incur any costs related to the maintenance of the heat pump.

Summary of the findings derived from the economic analysis included in stage IV of task D4.3

The main findings derived from the application of this task are summarized in Tables 28 and 29.

Table 28. Main findings concerning the service packages from the key value network actors' perspective.

Actor	PSS service package	Smart PSS service package
Elm.leblanc	*I. Financing and maintenance (M1)*: Assuming that the remote diagnostic service is not offered to the customer, the cumulative profit as maintenance provider and per active subscription depending on the appliance type is: o Gas boilers= 188€ o Heat pumps= 199€	*I. Financing and maintenance (M1):* * Unrealistic assumptions used in the simulation. * Digital service delivery costs negatively impact gross profits. * Additional savings in maintenance operations needed. * If the Smart PSS package is offered for free to the customer, the cumulative profit per active subscription would be 31€ (assuming a monthly delivery cost per customer of 5€). *II. Leasing (M2) and rental (M3):* Smart PSS subscriptions increase the cumulative profits associated with the after-sales operations (under the assumption that the service provider decides that all appliances are monitored remotely).
Installer network	Installers make the traditional margin on the heating appliance purchase and installation service fees, in all the economic models.	Installers make an additional margin on the connectivity hardware in all the economic models.
Service provider	*I. Leasing (M2) and rental (M3):* Higher costs are expected without the remote diagnostic service due to a more significant number of service engineers' visits for operations that could be fixed remotely or would only require one visit instead of two.	*I. Financing and maintenance (M1):* The service provider makes a margin on the Smart PSS subscription. Their role is to be an intermediary between the customer and the maintenance provider. The latter delivers the remote diagnostic service. *II. Leasing (M2) and rental (M3):* The service provider pays an annual subscription to the Smart PSS service package. This subscription is aimed at lowering the maintenance costs of the heating appliance fleet. However, according to the simulation results, the savings do not outweigh the remote diagnostic subscription costs for the service provider.
Private homeowner	*Peace of mind about the heating appliance being taken care of quickly in case of a breakdown. * No monetary benefits guaranteed: the remote diagnostic service is advertised as being able to support private homeowners in controlling their energy consumption. However, no energy savings are guaranteed, and energy cost was not included in this case study.	

Table 29. Main findings concerning the economic models from the perspective of key value network actors.

Actor	Financing and maintenance (M1)	Leasing (M2)	Rental (M3)
Elm.leblanc	*Economic model that generates the greatest cumulative gross profits in all configurations. *It heavily relies on government subventions for private homeowners aimed at heating system retrofit. * Heat pumps included which generate higher profits compared to gas boilers. * Monthly recurring revenues from the maintenance contract generate higher cumulative profits than hourly-based rate payments.	* Economic model with the second greatest cumulative profits in all configurations. * Heat pumps included. * Maintenance visits charged on an hourly-based rate (B2B context) reduce cumulative profits significantly compared to M1.	*The rental of gas boilers generates the lowest cumulative gross profits according to the simulation results. However, this economic model generated the highest operating margin in all input configurations. * Maintenance visits are charged at an hourly-based rate (B2B context).
Installer network	* Heat pumps included which generate higher gross profits for the installers compared to gas boilers.	*Economic model that generates the greatest cumulative gross profits in all configurations. However, this outcome is explained by the additional revenues considered from the heating appliance uninstallation in case customers did not buy the appliance for its residual value. These revenues are linked to the cancellation contract rate, an input parameter of aleatory nature. * Heat pumps included.	* This economic model generates the lowest cumulative gross profits for the installers. This outcome is explained by the fact that only gas boilers were considered in this economic model. These appliances generate lower profits for the installers compared to heat pumps.
Service provider	*Economic model that generated the second greatest cumulative gross profits. * The service provider makes a one-time margin on the heating appliance purchase and installation cost. * The service provider makes a recurring margin on the monthly subscription.	* The results displayed in Figure 68 did not consider capital costs related to the appliances acquisition and installation. Appliances' depreciation was not considered either for the sake of simplicity. These costs significantly reduce the service provider's net profits. * Maintenance costs of the heating appliance fleet affect the service provider's gross profits.	*Same aspects as in the leasing model (M2). * Lower cumulative gross profits due to lower subscription prices.
Private homeowner	* Customer owns the appliance. * Customer can claim government subventions. * Customer assumes the spare part costs. * Most expensive subscription price for heat pumps.	* Ownerless solution. * Customer does not assume any maintenance costs. * Most expensive subscription prices for gas boilers.	* Same aspects as in the leasing model (M2). * Cheapest subscription prices for gas boilers.

7.3.1.3.5 Task D4.3-Stage V: Sensitivity Analysis.

Discussion sessions were held with elm.leblanc's practitioners to analyse the key findings presented in the previous section. During these sessions, a list of input parameters that potentially have the most impact on the economic models' cumulative profits was defined. This list was used to formalize a new experimental plan to test the effect of the individual variation of these parameters on elm.leblanc's cumulative profits. This experimental plan is described in Table 30, while the results of the sensitivity analysis conducted to test these variations are shown in Figure 70. The scenario including the Smart PSS package, was simulated in all the economic models (i.e., M1, M2, and M3).

Table 30. Experimental plan for the sensitivity analysis.

Input parameter	Economic model(s)	Decreasing variation	Baseline configuration	Increasing variation
Market volume	M1, M2, and M3	-10 subscriptions per month	Demand curve is presented in Appendix II.2	+10 subscriptions per month
Product default rate	M1, M2, and M3	86% heating appliances with no faults (per year)	88% heating appliances with no faults (per year)	90% heating appliances with no faults (per year)
Remote diagnostic service price	M2 and M3 (annual fee)	48€	60€	72€
	M1 (monthly price)	4€	5€	6€
Distribution gas boiler and heat pump subscriptions	M1 and M2	65% Gas boilers 35% Heat pumps	75% Gas boilers 25% Heat pumps	85% Gas boilers 15% Heat pumps

From Figure 70, it can be noted:

o The most significant impact on the cumulative gross profit from elm.leblanc's perspective, is the distribution of gas boilers and heat pumps sold through the 'heating-appliance-as-a-service' subscriptions. As the rental model was modelled solely for gas boilers, this input parameter was not considered in this economic model.

o The second parameter having the second-largest impact is the market volume, in other words, the number of subscriptions sold. Each new subscription represents a revenue source for elm.leblanc for the sale of the heating appliance installed at the customer's home and for the maintenance service of this appliance. Therefore, this finding is not surprising. Both parameters are linked to market uncertainty.
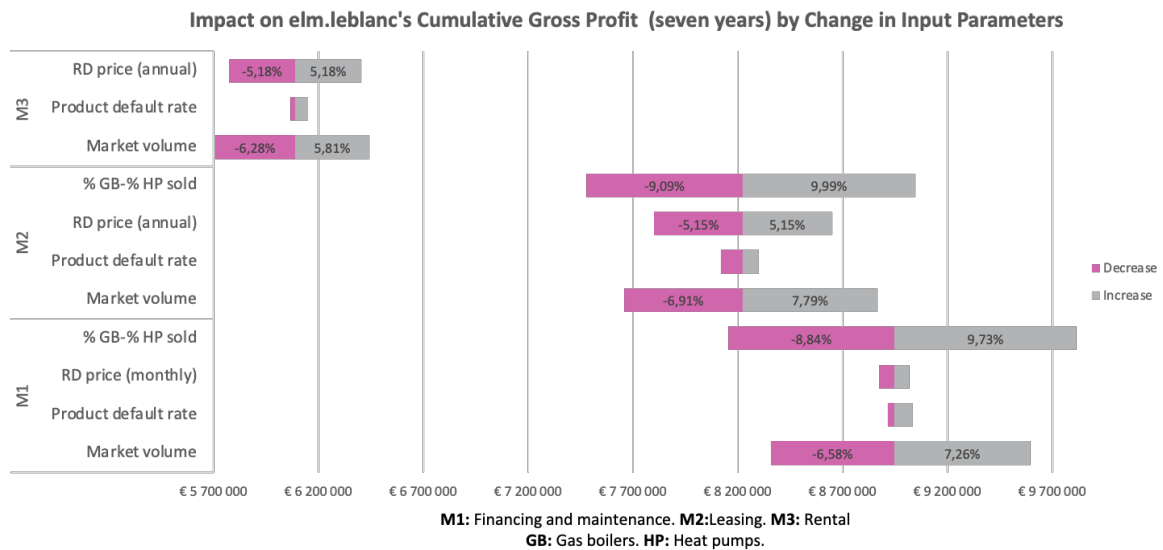
Figure 70. Sensitivity analysis results.

In sum, this economic analysis showed no evidence of financial losses for the key value network actors under the three simulated economic models. Nonetheless, it was noted that the achievement of the financial targets relied on input parameters associated with the subscription demand.

7.3.1.4 Task D4.4: Definition of risk mitigation strategies.

The key findings presented in the previous tasks showed that under specific conditions associated with the demand for heating-appliance- as-a-service subscriptions, elm.leblanc's profitability targets are not met. This demand uncertainty is mainly linked to three economic model inputs: the market volume of subscriptions sold per month, the distribution of gas boiler and heat pump subscriptions, and the subscription price.

The collaborative analyses identified government subventions for heating system upgrades as the most important external factor influencing the value of the previously mentioned input parameters.

o First, these subventions favour customer ownership, as only private homeowners can claim these subsidies. In this context, subventions benefit the product-oriented model, as the amount of the credit is reduced after subventions have been claimed. Hence, this reduction is reflected in the 'financing and maintenance' (M1) subscription price. On the contrary, these subventions make leasing subscription (M2) prices more expensive for gas boilers, as the service provider cannot benefit from these subventions. Besides, gas boilers are relatively cheaper than heat pumps, which may imply that the cost barrier for these appliances is not perceived as critical by potential customers. A fact that might back this hypothesis is the withdrawal from the market

of two financing and maintenance subscriptions (M1) for gas boilers proposed by two service providers in the French market.

o Second, as policymakers' decisions are ever-changing and influenced by the external context, changes in subsidy policies lead to re-examine the economic models' desirability by homeowners. This was the case with a government measure taken in March 2022 that declared the halt in subsidies for the purchase of gas boilers and the increase in the subventions for heat pump acquisition. These measures made re-evaluate these economic models. Due to the absence of subsidies for gas boilers, the leasing subscription prices for these appliances are likely to become appealing. In contrast, product-oriented subscriptions, including gas boilers, may become more expensive. Similarly, the increase in subsidies for heat pump purchases may favour the product-oriented subscription.

o Third, given the high purchase cost of heat pumps, opportunities may arise for heat pump leasing subscriptions (M2). In that case, it may be necessary to reinforce the communication of the leasing offering's customer value for the private homeowner (e.g., no unplanned maintenance costs) that may boost the desirability of the leasing subscriptions. However, the running costs for these appliances (energy cost) must be considered in the communication of customer value. High electricity and gas prices may hinder the desirability for heat pumps and gas boiler subscriptions, respectively, and influence the appliance choice included in the subscription.

Additionally, regarding the use-oriented economic models (M2 and M3), an extension of the Smart PSS contract's scope was proposed. In this contract, other than the remote diagnostic service, repairs (travel and labour fees) and a discount on spare parts are included. This proposition arose from two findings of the economic analysis. Firstly, it was noted concerning the maintenance operations that the recurring revenue model (monthly fixed fee) generated higher profits than hourly-based rates for specific activities. Secondly, the fourth stage of task D3 described how the Smart PSS package reduced the service provider's profits. Hence, the hypothesis is that this upgraded Smart PSS contract's scope may create added economic value for the service provider as the appliance feet owner and generate higher profits for the maintenance provider.

The conclusion of this task D4 led to defining the following actions to control these risks:

o A new set of simulation runs must be conducted to evaluate the economic performance of the economic models under two assumptions: (i) in the absence of subventions for gas boiler subscriptions and (ii) with higher subventions for heat pumps.

o Conducting additional interviews with private homeowners owning old heating appliances to deepen: (i) the understanding of their motivations to continue using gas boilers or switching to heat pumps, (ii) the factors they weigh to choosing a heating appliance technology, and (iii) their energy management routines.

o Collecting first-hand empirical evidence about the cost savings in the maintenance activities enabled by the remote diagnostic service (the input parameters used in the simulation

concerning this aspect were based on reports from the residential heating business). These data will be used in the new set of simulation runs.

7.3.2 Application of the methodological block E: Development and experimental prototyping of the Smart PSS solution

Once the design team decides to continue exploring the implementation of specific scenarios combining an economic model and a service package, the next step consists in developing a Minimum Viable Product (MVP) for the Smart PSS offering. This MVP is tested in a real-world setting to obtain valuable feedback before deciding to scale the commercialization of the Smart PSS offering. The tasks applied in this methodological block are described in section 5.7.

Task E5.1: Development of the Minimum Viable Product (MVP).

Elm.leblanc's gas boiler remote diagnostic service, called 'Optibox 2.0', is currently commercialized in the Business-to-Business market (social housing providers and after-sale service firms). The remote monitoring service and its associated digital platform are operational in a different customer segment from the one addressed in this case study. Therefore, the minimum viable product (MVP) for the packaged solution treated in this case study was available when applying the proposed Smart PSS design framework. Optibox's digital platform would have to be integrated with the service provider's. The latter platform would be in charge of receiving customer requests and handling billing and all the information concerning the customer. This integration is dependent on the decision-making process results, supported by the application of our proposal. In other words, if the focal firm and the service provider agree to launch one or various subscriptions, it will be necessary to integrate both digital platforms.

The remote monitoring service's usability, technical feasibility, and product connectivity capabilities were tested and validated before this case study development. This MVP was developed by employing the guidelines of the agile method Scrum, which is already incorporated in the focal firm's design and development routines. Hence, the validation of the methods and tools included in this methodological block are not the focus of this case study.
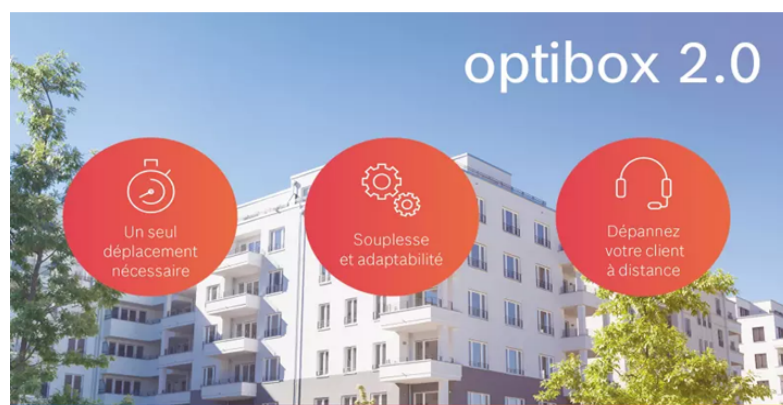
Figure 71. Optibox advertising aimed at social housing companies.

The inclusion of 'Optibox 2.0' in the packaged solution implies the involvement of an actual minimum viable ecosystem (MVE). This initial MVE gathers the actors involved in the digital service delivery. Concerning the rest of the actors required to build the MVE to deliver the packaged solution, we can mention that elm.leblanc currently has the capabilities to manufacture and distribute the heating appliances to wholesalers, in addition to its after-sales department. Moreover, an established partnership between elm.leblanc and a group of installers trained and certified by the manufacturer eases the MVE's development. Further details about the MVE development cannot be disclosed for confidentiality reasons.

Task E2: Testing, verification, and validation of the MVP.

Two experimentations are considered in this task. On the one hand, the feedback obtained from implementing the 'HaaS' product- and use-oriented economic models by Bosch Group in the German market since September 2020 are used as testing results for our case study. These testing results provide insights into the offering's acceptability in the European market, even though the French market may have different characteristics that would require additional experimental tests. On the other hand, competing after-sale companies currently subscribe and pay for the remote monitoring service. The feedback from these companies brings evidence that Optibox's operation could generate internal maintenance savings if elm.leblanc's after-sales department implemented Optibox in their activities.

Task E3: Risk review.

The main risk identified in this review was the operational difficulty in integrating Optibox's platform with an external platform owned by a third-party (e.g., the service provider). Failing to incorporate these platforms would lead to delays in launching the offering.

Conclusions

This chapter illustrates the application of the proposal introduced in Chapter 5 and the supporting tools detailed in Chapter 6 in a case study involving the private homeowner customer segment and the retrofit of individual heating systems. The proposal's validation process through this case study spanned from June 2020 to February 2022. A group of internal stakeholders from diverse elm.leblanc's departments participated in this validation phase. External experts and Bosch professionals also contributed with their insights.

The proposal is composed of two iterative loops. In the iterative design loop, a conceptual modelling approach was employed with the support of the IT tool called sPS^{2}Modeller. The conceptual models created in this loop shed light on aspects such as (i) the subscription's structure (e.g., the conditions to terminate the subscription, the customer obligations), (ii) the required value network configurations to deliver the all-inclusive subscriptions, (iii) the actors responsible for customer acquisition (hypothetically assigned to a third-party), (iv) and the product and service features needed to deliver the Smart PSS offering (e.g., product compatibility with the connectivity hardware, easiness to install, uninstall and refurbish).

Moreover, three main innovation risks were detected in this design loop. First, the customer's undesirability of ownerless all-inclusive subscriptions because of the generous government subsidy schemes to purchase new heating appliances. Second, we can mention the probability of not finding enough installers willing to integrate the value delivery network or not being able to recruit enough technicians to carry out the maintenance operations. Lastly, the customer unwillingness to pay for the remote diagnostic service as they may not perceive this digital service's value.

The iterative validation loop's application was supported by an IT tool called sPS^{2}Simulator, presented in Chapter 6. This loop allowed the design team to obtain insights into the potential economic performance of the economic models that deliver the value proposition. Three main viability risks were identified in this loop: (i) poor subscription sales due to factors such as the pricing, long subscription periods, and alternative solutions like government subsidies for heating appliance retrofit, and (iii) digital service's unprofitability due to high delivery costs and insufficient cost savings (e.g., reduced number of service engineers' visits and shortened repair time), and (iii) external factors that affect the demand for gas boilers and heat pumps separately.

This proposal was perceived to be easy to implement and use by the practitioners participating in this validation process. The experimentation presented in this chapter confirmed the proposal's applicability, enabled by the inclusion of methods with which the focal firm's professionals are familiar. Concerning the case study presented in this chapter, it is worth mentioning that even if the value networks introduced in this chapter have few actors involved, the proposal can be conveniently employed with more extensive value networks. Further validation with more complex value networks (e.g., all-inclusive solutions covering heating, ventilation, and air-conditioning functionalities) is required to confirm the proposal's practicability with more sophisticated service packages.

Practitioners also highlighted the supporting tools' usability in their work practices. However, it is essential to note the limitations of these tools in the proposal's application. First, additional skills within the design team members are required to fully operationalize the proposal in the focal firm's activities—specifically, computer skills in coding for the simulation platform development and maintainability. Second, the economic analysis may be time-consuming due to the number of simulation runs required and the dashboards' evolution to include new indicators. Third, the quality of the simulation results depends on the input parameters' accuracy. Collecting these values may be challenging at the early design stage, primarily with the economic parameters related to external actors.

Nonetheless, the simulation platform presented in this thesis is a mock-up that will be used as the foundation for a more advanced IT tool that will be integrated into the focal firm's practices. This advanced tool is expected to ease the simulations' result generation and the comparative economic model dashboard. The conclusions and perspectives of this thesis are presented in the following chapter.

Chapter 8. Conclusions and perspectives

8.1 Findings and results

The general problem addressed in this thesis concerned the development of a Smart PSS design framework that dealt with two main gaps identified in the literature. These gaps matched elm.leblanc's industrial needs. The first gap regards the holistic consideration of the adjustments needed in the value processes (i.e., the value proposition, the value delivery network, and the value capture mechanism) of the product-based firm. Accordingly, the second gap addresses the integration of the innovation risk management process into the early design phase of the Smart PSS offering.

The sPS^{2}Risk framework was built to address these gaps that have not been considered in the existing Smart PSS design methodologies. This design framework was developed over three years thanks to the collaboration and feedback from the professionals of elm.leblanc. In order to make the sPS^{2}Risk framework applicable in the design routines of elm.leblanc, two customized IT tools were developed: the sPS^{2}Modeller and the sPS^{2}Simulator. These tools aim to support the implementation of the different methodological blocks of the proposal. The sPS^{2}Modeller is a software program that enables the creation of digital prototypes. The sPS^{2}Simulator is a computer-based tool that estimates key economic performance indicators associated with alternative Smart PSS value delivery networks, from the perspective of each key value network actor.

Our proposal suggests a preliminary strategic contextualization step before applying the sPS^{2}Risk framework. The aims of this initial step are threefold. First, it aims to diagnose the weaknesses and strengths of the industrial firm concerning the transition to becoming a Smart PSS solution provider. Second, in this step, the critical stakeholders concerned about the transformation of the product-based offering into a Smart PSS offering are identified. This step employs the sPS^{2}Modeller to map the stakeholders of the product-based business ecosystem. Third, the customer segment targeted by the digital servitization efforts is defined. Then, we suggest applying the sPS^{2}Risk framework to design the Smart PSS solution.

The sPS^{2}Risk framework is a closed-loop design methodology that comprises five methodological blocks. Each methodological block is made up of a series of tasks detailed step by step in Chapter 5.

The first methodological block (A), called 'Elicitation of key stakeholders' value expectations,' employs widespread tools used in the 'understand,' 'observe,' and 'define a point of view' phases of the Design Thinking approach. This methodological block aims at collecting and eliciting key stakeholders' needs in a structured manner. The main output of this methodological block can be summarized as the 'customer profile' for each key stakeholder. Osterwalder et al. (2014) proposed this' customer profile' in their Value Proposition Design guidelines, consisting of 'customer jobs, gain and pain points'.

These 'customer profiles' are the basis for designing the Smart PSS value proposition that is the primary outcome of the methodological block B. This methodological block is called 'Prototyping of the general value concept'. Tools widely used in the 'ideate' phase of the Design Thinking approach and the generation of conceptual prototypes are the core of this methodological block. These conceptual prototypes represent key elements of the Smart PSS value proposition; specifically, the products and services (basic and digital) included in the offering, the demand related to the customer segment and the value proposition, and the value offering. These prototypes are created with the sPS^{2}Modeller and are used as thought-provoking cognitive supports to facilitate the identification of innovation risks and the design of risk mitigation strategies.

The third methodological block (C), called 'Specification of the detailed value concept', aims at configuring the multiple potential alternative value networks to deliver the value proposition designed in the methodological block B. This methodological block adapts the Value Network Design guidelines (Kage et al., 2016) to generate prototypes that guide the draft of the potential Smart PSS value delivery networks. These prototypes are created on the sPS^{2}Modeller and are also used as cognitive supports to identify and mitigate innovation risks, mainly the feasibility risks that could lead to adverse events such as failed partnerships and difficulties in information and knowledge sharing.

The information collected and the insights represented on the prototypes elaborated in the preceding methodological blocks are the primary inputs to implement the methodological block D, called 'Simulation and decision-making applied to the Smart PSS design'. This methodological block estimates the profitability associated with each alternative Smart PSS value network from a multi-actor perspective. This economic evaluation aims to provide decision-makers with evidence about the potential monetary value captured through the Smart PSS offering's commercialization. Moreover, this evaluation indicates the win-win conditions for the key actors required to build the Smart PSS value delivery network. The simulation outcomes support the strategical decision-making process concerning the selection of the Smart PSS economic models and the service packages that should be included in the Smart PSS value proposition.

Lastly, the fifth methodological block (E) is called 'Development and experimental prototyping of the Smart PSS solution.'. This methodological block addresses the construction of a Minimum Viable Product (MVP) and a Minimum Viable Ecosystem (MVE) that are then tested with a group of customers.

It aims to obtain valuable feedback that supports the decision-making concerning the implementation of the Smart PSS offering in the market and its scalability. Table 31 summarizes the contributions of this thesis by showing the research questions that guided the research work and how these questions were answered.

Table 31. Summary of the contributions of this thesis.

Research question	Solution
<u>General research question:</u> How to define and formalise a framework aimed at helping the stakeholders of Smart PSS design projects to anticipate and mitigate major innovation risks from the Business Model Innovation and Value-Driven design perspectives?	<u>Formulation of the sPS²Risk Smart PSS design framework:</u> This framework fits the value-driven perspective described by Zheng et al. (2019). This framework aims to concurrently support the design of the value Smart PSS proposition, the alternative Smart PSS value networks, and the potential profit mechanism originating from the Smart PSS commercialization. The sPS²Risk framework consists in a preliminary strategic contextualization step and five methodological blocks. This proposed framework is detailed in Chapter 5.
<u>Research Question No1</u>: How to develop a prototyping approach and its supporting implementation tool, which would bring a consistent solution to meet designers' needs concerning the visualization of the design object and innovation risk anticipation during the early Smart PSS design phase?	<u>Development of the sPS²Modeller:</u> This IT tool generates the prototypes necessary to implement the strategic contextualization step and the methodological blocks B and C. These methodological blocks respectively address the design of the Smart PSS value proposition and the configuration of the potential value networks that can deliver this value proposition. Further description of this IT tool is provided in section 6.1.
<u>Research Question No2:</u> How to develop an economic performance simulator to evaluate the viability of alternative Smart PSS delivery networks and assist the decision-making process in the design phase?	<u>Development of the sPS²Simulator:</u> This economic performance simulation tool was built to enable the implementation of the methodological block D. Based on the prototypes generated by applying the three first methodological blocks of the proposed framework, the methodological block D estimates the profitability of each alternative Smart PSS value network. This profitability is calculated from the perspective of each key value network actor. The outcomes of this simulation tool are used as input for the decision-making process related to selecting the Smart PSS economic models that should be implemented to commercialize the Smart PSS offering.

8.2 Main contributions and implications

The systematic design of Smart PSS offerings is a relatively new research subject due to the novelty of the Smart PSS concept. For established manufacturing firms, the shift from the one-off sale of products and the sale of services alone to the commercialization of Smart PSS offerings entails a Business Model Innovation (BMI) process. In this perspective, modifications to the firm's value architecture (i.e., the value proposition, the value delivery network, and the profit mechanism) and the emergence of innovation risks are unavoidable. We developed a novel Smart PSS design framework to address these issues.

8.2.1 Scientific contributions

Based on this observation, the originality of our Smart PSS design framework is twofold. First, this framework concurrently addresses and supports: (i) the design of the Smart PSS value proposition, (ii) the configuration of alternative value networks to deliver this value proposition, and (iii) the estimation of the profitability generated from the sale of the Smart PSS value proposition through the alternative value network options. As a whole, the sPS^{2}Risk framework aims at supporting the strategic decision-making process concerning the selection of the Smart PSS economic model. To our knowledge, Smart PSS literature lacks methodologies that encompass the four dimensions of the Business Model Innovation described by Gassmann et al. (2014). Existing Smart PSS design frameworks focus on one or two of these dimensions, while the profit mechanism is the least addressed dimension in Smart PSS design.

Second, the sPS^{2}Risk framework integrates a flexible risk management approach. This flexible approach aims to identify and mitigate the innovation risks originating from the digital servitization efforts made by the product-based manufacturing firm. To this end, the standard qualitative risk management approach was incorporated as a task in the methodological blocks B, C, and E. Furthermore, a quantitative approach to assess the financial viability risks is the core of the methodological block D. The purpose of the inclusion of these risk analysis methods in the Smart PSS design framework is to assist decision-makers with evidence about the profit generated from the Smart PSS commercialization. This evidence is expected to prevent decision-makers from putting Smart PSS offerings in the market that might negatively affect the manufacturing firm's financial health. The notion of risk has been scarcely addressed in the Smart PSS literature, despite the apparent importance of mitigating the innovation risks associated with the transition from a product- to a service-based and digital-enabled value proposition.

The sPS^{2}Risk framework was conceived to be a pragmatic design methodology in line with the suggestions by Abramovici et al. (2015). Hence, widespread methods and tools, such as Design Thinking and Value Network Design, were adapted and included in the proposed design framework to facilitate its understanding by practitioners. The applicability of the sPS^{2}Risk framework in the operations of elm.leblanc was supported by the development of two customized IT tools. These tools are called the sPS^{2}Modeller and the sPS^{2}Simulator.

The sPS^{2}Modeller is a modelling toolkit that enables the creation of digital prototypes. These digital prototypes consist of conceptual models representing the system's main elements needed to develop the Smart PSS offering. Specifically, the aspects that concern the Smart PSS value proposition and its associated value delivery networks. These conceptual models are based on a PSS engineering modelling language proposed by Medini and Boucher (2019) that was extended and adapted for the Smart PSS design context.

The models created on the sPS^{2}Modeller employ the Visual Thinking technique to serve as cognitive support to facilitate the identification of innovation risks. These models are intuitive, which eases the

communication among the firm's internal actors and external stakeholders. In addition, these models aim to support the decision-making process at an operational level concerning the contract design, the product and service design, the marketing of the Smart PSS offering, and the network relationships management. Lastly, this modelling toolkit serves as a knowledge repository to store the data needed to formulate the economic models associated with the alternative Smart PSS value networks. These economic models are simulated on the sPS^{2}Simulator.

The sPS^{2}Simulator is a simulation tool tailored to the industrial case study. This tool estimates the value of a group of economic performance indicators associated with the alternative Smart PSS value networks. This simulation tool considers dynamic aspects such as the market volume of the Smart PSS subscriptions and the product's failure rate to calculate these values. Thus, the variability of a set of input parameters of the economic model is included in the economic performance assessment. This simulator is employed in the methodological block D of the sPS^{2}Risk framework, specifically to perform the scenario analysis. These scenarios address the alternative value networks under several input parameter configurations to test the resilience of the economic models regarding simultaneous variations of the input parameters.

Additionally, the simulator allows practitioners to apply the Monte-Carlo simulation technique in each scenario assessed. Consequently, practitioners can visualize the expected profit distribution for each key value network actor. The outcomes of the simulation plan are compelled in a comparative dashboard that supports decision-makers concerning the selection of the most attractive Smart PSS value networks in terms of profitability. As the literature lacks tools that demonstrate the monetary value generation for the actors involved in Smart PSS delivery, this gap was addressed in this thesis with the development of the sPS^{2}Simulator.

8.2.2 Practical implications

A manufacturing firm like elm.leblanc, whose business model is based on one-time transaction sales, often designs products and services separately. In contrast, the design of all-inclusive Smart PSS solutions requires a holistic perspective. Hence, professionals involved in product and service development must collaboratively develop Smart PSS solutions. This transdisciplinary collaboration represents a shift in the design routines of the manufacturing firm. In this regard, to support this shift, the sPS^{2}Risk framework was conceived to be used by a cross-functional design team. This proposed design framework can help elm.leblanc's professionals with the following activities:

(i)   Collect and identify the key stakeholders' needs in a structured manner

(ii)   Outline the Smart PSS value proposition and its associated value offering by using the modelling toolkit called sPS^{2}Modeller

(iii)   Configure alternative value networks to deliver the Smart PSS value proposition through the tailored modelling toolkit

(iv)   Conduct risk management activities to mitigate the main desirability, feasibility, and viability risks associated with the commercialization of the Smart PSS offering

(v)   Estimate the profitability of the alternative value networks from a multi-actor perspective

(vi)   Refine the Smart PSS value proposition and the alternative value delivery networks based on the innovation risks identified and controlled during the application of the sPS^{2}Risk framework

The proposal's applicability within the activities of elm.leblanc was tested through an industrial case study reported in Chapter 7. This case study and the interactions between practitioners and scholars during this thesis helped elm.leblanc gain greater maturity in designing Smart PSS offerings. The feedback from elm.leblanc's professionals indicated that applying the sPS^{2}Risk framework enabled the detection of risk sources that could jeopardize the company's servitization efforts. A particular emphasis was made on the mitigation of the financial viability risks. Concretely, the case study results led to formulating managerial recommendations for elm.leblanc to reduce the identified risks.

These recommendations included:

(i)   The conduction of additional interviews with potential customers to deepen the understanding of their motivations to subscribe to the 'heating appliance as a service' offering designed through the case study.

(ii)   The collection of additional information about the indirect value captured through the remote diagnostic service for heating appliances.

(iii)   The simulation of the alternative value networks with a new set of input parameters considering the recent changes in the subsidy policies for the purchase of gas boilers and heat pumps.

As a result of applying the proposed Smart PSS design framework, elm.leblanc obtained evidence about the potential profitability of commercializing service-based offerings under alternative economic models and including different service packages.

According to the professionals' feedback, these risk sources could have probably gone undetected by following an unstructured design approach. Moreover, this feedback highlighted the easiness of using and implementing the proposed design framework and the usability of the customized IT tools. These IT tools facilitated communication among the various internal actors and the common understanding of the design goals. As for the utilization of the economic performance simulation tool employed in the methodological block D, it was noted that this activity was time-consuming. This situation is due to the simulation run times and the compilation of the simulation outcomes to create a comparative dashboard. This simulation tool was a first mock-up that is planned to set a basis for a generic simulation platform for the design of Smart PSS offerings related to the activities of elm.leblanc. Other research perspectives and the limitations of this research work are detailed in the next section.

8.3 Limitations and future research

The proposal presented in Chapter 5 and the supporting tools described in Chapter 6 were applied to a case study involving the residential heating industry. In the short term, the proposal can be used to design offerings concerning other core activities of elm.leblanc (i.e., air conditioning and domestic hot water production) and different customer segments (e.g., industrial, and collective residential heating). Moreover, the scope of this thesis can be extended in further research, and we describe them as perspectives of this research work.

8.3.1 Limits of the study

The research work developed in this thesis has some limitations that we recognized. We mention these limitations from three perspectives: the research process, the standardisation of the proposal within elm.leblanc's activities and the application of the economic performance assessment, which is described in Chapter 6.

Concerning the research process: The proposed Smart PSS design framework was validated through a single case study. Hence, further validation is required to increase the cross-sectorial proposal's replicability. However, the scope of this thesis was the residential heating business. The proposal's application to other case studies would require adapting the supporting IT tools presented in Chapter 6. In this regard, a potential extension of this research work emerges. This extension would concern the development of a generic conceptual modelling platform and a generic simulation platform for the design of Smart PSS solutions related to thermal comfort and domestic hot water provision. Nevertheless, the development of a generic economic performance simulator remains challenging since the development of this tool heavily relies on the case study's particularities.

Concerning the standardisation of the proposal within elm.leblanc's activities. The development of a standardised integration process of the proposal into elm.leblanc's design organisational routines was not included in the scope of this thesis. In this respect, further collaboration with elm.leblanc would be needed to validate the generalizability of the proposal for the design of smart thermal comfort solutions. Accordingly, the proposal's implementation was carried out as a 'pilot study,' and the results were reported in Chapter 7.

Concerning the economic performance assessment. Three limits can be identified from this part of the thesis, precisely on the application of the methodological block D:

The accuracy of the quantitative economic simulation outputs largely depends on the quality of the economic model's value inputs. The collection of these data can be burdensome due to access difficulties. For instance, external actors might be reluctant to share their costs and markup data. In order to overcome this difficulty, the results of the economic performance evaluation were based on the values of inputs available from public sources. However, these values might not represent reality thoroughly.

- The value of several economic models' inputs is inherently uncertain. For this reason, probability distributions were assigned to input parameters such as the monthly market volume and the product's

failure rate. However, these distributions were not given to other key input parameters, such as the multiple costs included in the profit equations. In this regard, a statistical analysis can be performed on historical data to determine the probability distribution that fits the variability nature of these costs. This would enable the consideration of the volatility of these costs, especially in light of recent events such as the global supply chain disruption that affected the manufacturing and spare part supply costs.

- Our economic performance assessment considered an infinite capacity industrial system. This means that no restrictions concerning the value of key resources such as the number of service engineers and installers were considered. This choice was made considering that the primary goal of our assessment was to support the strategical decision-making concerning the selection of the most profitable value network(s) to deliver the Smart PSS value proposition. In this regard, the economic assessment reported in this thesis can be enriched by realistically modelling the industrial system. In other words, our economic assessment can be extended by considering operational performance indicators of the value network actors.

These limitations represent opportunities to conduct further research, as described in the following subsection.

8.3.2 Future research perspectives

The aspects uncovered in this thesis that represent new research directions can be grouped into three categories: the estimation of generated sustainable value, the sustainable multi-actor decision-making process, and the economic and environmental performance assessment computer-based tool.

Estimation of generated sustainable value. The performance evaluation carried out during the application of the methodological block D of the sPS^{2}Risk framework solely dealt with the economic dimension. The other sustainability dimensions (environmental and social) were not included in this performance evaluation since the primary objective was to assess the financial viability of the alternative Smart PSS value delivery networks. Nonetheless, we acknowledge the importance of evaluating these sustainability dimensions. In this regard, a research project aiming at coupling the economic and environmental performance assessment in the early design phase was launched as part of the industrial chair CORENSTOCK (https://www.mines-stetienne.fr/recherche/chaires/chaire-industrielle-corenstock/). This research project is applied to the design of Smart PSS solutions in the residential heating business.

The environmental performance assessment of Smart PSS solutions poses two main challenges. First, a large amount of technical data is required to evaluate the environmental impact of the Smart PSS solution during its entire lifecycle. However, collecting these data in the early design phase is demanding. The scarcity of the required data in this phase is explained by the technical elements of the Smart PSS solution that are being developed and tested in this design phase, which makes the assessment task difficult. Hence, historical data is unavailable, and input data values are highly uncertain. Therefore,

the environmental performance evaluation must be conducted using an uncomplicated method that requires a limited amount of input data.

Second, the formulation of performance indicators related to the environmental impact of digital technologies is a recent topic in literature. It is therefore difficult to select appropriate environmental performance indicators that measure the impact of delivering digital services through technologies such as the Internet of Things.

Sustainable multi-actor decision-making process. As stressed in the previous category an extension of the scope of this performance assessment requires the selection of key indicators covering the remaining sustainability dimensions. The choice of these indicators must be made considering the objectives of the decision-making process in a multi-actor perspective. For instance, these objectives could imply selecting the most profitable Smart PSS value delivery scenario with a low environmental impact or selecting the value delivery scenario with the lowest environmental impact while meeting a profitability threshold for each key stakeholder. This condition increases the complexity of the decision-making process by adding a multi-criteria perspective to the multi-actor perspective addressed in this thesis.

Economic and environmental performance assessment computer-based tool. A simulation tool was developed in this thesis to evaluate the economic performance of the Smart PSS offering. This tool predicts the value generated from the alternative Smart PSS value networks in monetary terms. Given the abovementioned research perspectives, an updated version of this IT tool could be developed. This version should be customized to the context of the Smart PSS design for heating, hot water production, and cooling solutions (the core activities of elm.leblanc). This updated version should be able to simulate both the economic and environmental performance of the alternative Smart PSS value networks relying on different physical products. Accordingly, this tool should enable practitioners to evaluate the trade-offs between the economic and environmental dimensions.

Résumé de thèse en français

Chapitre 1. Introduction.

De nombreux fabricants ont transformé leurs offres de valeur basées sur la vente séparée de produits et de services en propositions de valeur orientées vers le service, caractérisées par la vente d'une fonctionnalité au lieu d'un produit. Dans la littérature, ces propositions de valeur sont connues sous le nom de 'Systèmes Produits-Services' (PSS). Récemment, l'application de technologies numériques pour fournir les fonctionnalités des offres PSS a créé un nouveau paradigme traité dans la littérature sous le nom 'Smart PSS'. Du point de vue d'une entreprise centrée sur la vente de produits, la conception des offres Smart PSS implique un processus d'innovation du modèle d'affaires (Frank et al., 2019). En conséquence, dans ce processus de création d'une nouvelle offre de valeur de type Smart PSS, les entreprises doivent apporter des changements à au moins deux des quatre dimensions de leur modèle d'affaires. Ces quatre dimensions définies par Gassmann et al. (2014) sont le segment client, la proposition de valeur, le réseau de valeur, et le mécanisme de capture de valeur. Cependant, la littérature manque de cadres méthodologiques de conception des offres Smart PSS qui abordent ces dimensions simultanément. La plupart des cadres méthodologiques disponibles se concentrent sur une ou deux de ces dimensions. L'estimation de la valeur monétaire générée par la commercialisation de l'offre Smart PSS est la dimension la moins abordée par ces cadres méthodologiques actuellement disponibles.

En outre, dans ce processus d'innovation de l'offre de valeur, les entreprises font face à l'apparition des risques d'innovation (Osterwalder et al., 2020). Cela s'explique en raison du caractère innovant de l'offre Smart PSS dans le catalogue d'offres de valeur du fabricant. Ces risques d'innovation concernent l'adaptabilité aux menaces externes, la désirabilité de l'offre Smart PSS par les clients potentiels, la faisabilité pour fournir l'offre, ou encore sa viabilité économique. L'occurrence de ces risques peut soit entraîner des pertes financières dérivées de la commercialisation de l'offre Smart PSS, ou bien empêcher d'atteindre les objectifs financiers des parties prenantes. Ces scénarios possibles sont traités dans la littérature sous le nom du 'paradoxe de la numérisation' (Gebauer et al., 2020). Malgré les efforts de recherche pour comprendre comment les entreprises industrielles peuvent éviter ce phénomène, le management des risques d'innovation dans l'étape de conception des offres Smart PSS n'a pas été abordé.

Cette thèse vise à adresser l'approche de conception holistique des dimensions du processus d'innovation du modèle d'affaires et l'inclusion du management des risques d'innovation dans l'étape de conception. Pour ce faire, un cadre méthodologique de conception des offres Smart PSS est proposé dans cette thèse. Ce cadre méthodologique est le résultat d'une collaboration de recherche interactive avec l'entreprise elm.leblanc, fabricant d'appareils de chauffage. Afin de permettre l'opérationnalisation du cadre méthodologique proposée dans les activités d'elm.leblanc, deux outils informatiques ont été développés dans le cadre de cette thèse. Ces outils ont deux objectifs. Le premier objectif est d'accompagner les professionnels d'elm.leblanc dans la modélisation qualitative des éléments du système associés à l'offre Smart PSS. Le deuxième objectif est de simuler la performance économique

des réseaux de valeur alternatifs pour fournir l'offre Smart PSS, depuis le point de vue de principaux acteurs impliqués.

Chapitre 2. Éléments d'état de l'art sur les offres de valeur Smart PSS et la servicisation numérique.

La servicisation numérique est le processus organisationnel de transformation dans lequel les entreprises, dont le modèle de revenus est basé sur la vente transactionnelle des produits et services, commencent à vendre des offres de valeur Smart PSS de manière servicielle. Ces offres sont composées de produits, services physiques et services numériques, ce qui augmente la complexité du processus de conception. Afin de réduire cette complexité, la littérature a conclu que l'application d'un cadre de conception structuré est nécessaire. Pour cette raison, de nombreux chercheurs ont proposé des cadres méthodologiques pour la conception d'offres PSS. Contrairement au domaine du PSS, la conception d'offres Smart PSS n'a pas encore acquis de maturité suffisante.

Abramovici et al. (2015) ont proposé d'étendre les méthodologies de conception actuelles du PSS et de les adapter aux particularités du Smart PSS. Parmi ces particularités, ces auteurs citent : (i) l'apparition de nouvelles parties prenantes, (ii) l'émergence de nouveaux modèles d'affaires et de partage des risques parmi les parties prenantes dans les réseaux de valeur, (iii) et une interaction plus forte entre le fournisseur de l'offre et le client. Zheng et al. (2019) ont classifié les cadres méthodologiques de conception du Smart PSS selon deux perspectives. La première perspective concerne les aspects techniques de la fourniture du Smart PSS, par exemple, la capture des données à partir des capteurs installés dans les produits et le traitement de ces données pour fournir la fonctionnalité du Smart PSS. L'objectif principal de la deuxième perspective réside dans le processus de cocréation de la valeur, d'un point de vue axé sur la valeur pour les parties prenantes.

Cette deuxième perspective est abordée dans cette thèse puisqu'elle répond aux lacunes en recherche identifiées et aux besoins industriels collectés de la société elm.leblanc. Le secteur d'activité de cette société est en train d'évoluer avec l'adoption de multiples variantes d'un modèle d'affaires connu sous le nom de 'Heat-as-a-Service'. Dans les variantes de ce modèle d'affaires, un abonnement tout compris est proposé aux clients. Autrement dit, les clients payent une redevance mensuelle pour la disponibilité et l'entretien de l'appareil de chauffage connecté, au lieu de faire un paiement unique pour l'achat de l'appareil. De plus en plus, ces abonnements incluent des services numériques tels que le suivi à distance de l'appareil et le suivi de la consommation d'énergie.

Dans le passé, elm.leblanc a offert le service de suivi à distance nommé 'Thermibox', en complément du contrat après-vente classique. Cependant, ce service numérique n'a pas eu le succès commercial escompté et a été retiré du catalogue de services de l'entreprise. En considérant cette expérience d'elm.leblanc, nous avons adopté une orientation vers le management de risques d'innovation dans le cadre méthodologique de conception proposé dans cette thèse. Le but d'adopter cette orientation est d'éviter la mise en place sur le marché d'une offre Smart PSS qui ne répondrait pas aux objectifs

financiers, et qui par conséquent pourrait affecter la santé financière de l'entreprise. La revue de la littérature a montré qu'il n'existe pas de cadres méthodologiques de conception pour des offres Smart PSS qui abordent simultanément les aspects traités par la proposition conceptuelle de cette thèse. D'un côté, nous abordons les dimensions du processus d'innovation du modèle d'affaires (le segment client, la proposition de valeur, les réseaux de valeur, et l'estimation de la valeur économique capturée). D'un autre côté, nous intégrons le management des risques d'innovation visant à empêcher qu'un résultat commercial négatif ne se produise comme dans le cas de 'Thermibox'.

Chapitre 3. Les approches de prototypage conceptuel dans la conception axée sur la valeur des offres Smart PSS.

Comme indiqué dans le chapitre précèdent, la conception des offres Smart PSS est un processus complexe. Afin de faciliter ce processus, les professionnels ont besoin d'outils permettant la visualisation de l'ensemble du système et de ses sous-composants (Valencia Cardona et al., 2015). Pour répondre à ce besoin, la technique de prototypage a été utilisée dans la conception des offres PSS et Smart PSS (Exner et al., 2014 ; Ilg et al., 2018). Plusieurs outils graphiques bien établis tels que l'expérience client, l'analyse fonctionnelle, la matrice d'affaires proposée par Osterwalder et al. (2010), et la simulation par ordinateur, ont été employés dans la littérature du PSS.

Dans leur revue de littérature sur le prototypage des offres PSS, Ilg et al. (2018) ont conclu que la démarche de conception de ces offres orientées vers le service demande l'utilisation de divers types de prototypes, en fonction de la phase du processus de conception abordée. La création de prototypes dans le contexte de la conception des offres PSS est connu dans la littérature sous le nom de 'modélisation des PSS'. Phumbua et Tjahjono (2012) ont classé ces techniques de modélisation PSS selon trois catégories prenant en compte les perspectives des utilisateurs de l'offre, le système PSS, et le bouquet produit-service. Dans la revue de littérature présentée dans ce chapitre, nous nous sommes concentrés sur les techniques considérant la perspective du bouquet produit-service.

Ce choix a été motivé par trois raisons. D'abord, la perspective considérant exclusivement les interactions avec le client n'aborde pas l'ensemble de besoins de prototypage identifiés. Ces besoins concernent notamment le prototypage des éléments constituant la proposition de valeur et le réseau de valeur. Deuxièmement, l'élaboration de prototypes de basse résolution est appropriée au début de l'étape de conception où le niveau de maturité est bas (Karagiannis et al., 2022). Finalement, la perspective du système, caractérisé par l'utilisation des techniques de simulation est traitée dans le Chapitre 4.

Étant donné ces considérations susmentionnées, nous avons retenu la modélisation conceptuelle comme technique appropriée pour : (i) représenter le segment client, (ii) aider la conception de la proposition de valeur Smart PSS et (iii) configurer des réseaux de valeur alternatifs pour fournir l'offre Smart PSS. De plus, à partir de la revue de littérature nous avons retenu deux éléments principaux :

- D'un côté, les prototypes crées dans cette étape du processus de conception doivent être intuitifs afin de servir de support cognitif pour faciliter l'identification et la conception des stratégies de mitigation des risques d'innovation. Notamment, avec l'apport de ces prototypes, nous cherchons à stimuler la génération des informations sur la désirabilité et la faisabilité de l'offre Smart PSS. Par conséquent, les représentations graphiques doivent être faciles à comprendre par les concepteurs. A cet égard, la création d'un langage de modélisation spécifique pour la conception des offres Smart PSS est une perspective intéressante de prototypage.

- D'un autre côté, les prototypes élaborés dans cette étape du processus de conception doivent être faciles à créer et à modifier à un moindre coût. Ainsi, la création de ces prototypes devrait être facilitée par un outil informatique visant à permettre l'élaboration agile des prototypes et le partage des informations nécessaires pour simuler la performance économique de l'offre Smart PSS.

Chapitre 4. Évaluation économique quantitative des offres Smart PSS.

La définition des équations de bénéfices est indispensable pour tout type d'offres. Cela implique que les estimations de la structure de coûts et des revenus doivent faire partie du processus de conception des offres Smart PSS. A cet égard, la revue de la littérature nous a permis d'identifier deux éléments que nous avons retenu pour notre proposition conceptuelle. D'abord, du fait que l'offre Smart PSS est fournie par un réseau de valeur composé de plusieurs acteurs, l'estimation de bénéfices monétaires doit considérer la perspective du partage de la valeur économique parmi les acteurs. Autrement dit, les gains monétaires résultant de la commercialisation de l'offre Smart PSS doivent être estimés pour chaque acteur clé du réseau de valeur. Deuxièmement, tous les coûts et revenus générés pendant tout le cycle de vie de l'offre Smart PSS doivent être pris en compte. Donc, l'estimation des profits doit être effectuée dans une double perspective : cycle de vie et multi-acteurs.

Malgré l'importance de l'évaluation économique dans le processus de conception, Parida et al. (2019) ont conclu que l'estimation de la rentabilité des modèles d'affaires basés sur la vente des offres Smart PSS a été peu abordée dans la littérature. Ces auteurs soutiennent que de nouveaux risques apparaissent dans ces modèles d'affaires. Par conséquent, ces auteurs suggèrent l'inclusion d'approches flexibles de gestion des risques visant à gérer la présence d'incertitudes au début de la phase de conception. La revue de littérature nous a montré que la technique de simulation Monte-Carlo a été largement utilisée pour quantifier l'incertitude et les risques associés aux modèles d'affaires basés sur les services ; particulièrement, dans l'estimation de coûts pour fournir ce type d'offres (Erkoyuncu et al., 2013).

A partir de la revue de la littérature, nous retenons que l'évaluation économique doit intégrer des techniques quantitatives de management des risques et de l'incertitude. Ces techniques doivent permettre aux concepteurs de prendre en compte les facteurs dynamiques mentionnés par Phumbua et Tjahjono (2012), tels que les changements du marché, la défaillance des produits pendant l'usage de

l'offre Smart PSS, entre autres. Donc, l'évaluation économique doit considérer la variabilité des paramètres d'entrée du modèle économique dans l'estimation de profits. En outre, l'évaluation économique doit permettre aux décideurs industriels d'obtenir des éléments d'argumentation sur la viabilité économique d'une offre Smart PSS, déployée un modèle économique spécifique, au sein d'un marché particulier. Pour ce faire, la démarche de conception devrait inclure une aide à la décision permettant aux décideurs de visualiser la rentabilité associée à chaque réseau de valeur alternatif avant de son implémentation (Nakada et al., 2020).

La revue de la littérature nous a montré également que les techniques de simulation ont été largement utilisées pour évaluer les performances des offres PSS, y compris la performance économique. Néanmoins, concernant les offres Smart PSS, très peu de propositions pour évaluer sa performance économique sont disponibles. Donc, nous retenons que la simulation par ordinateur est une technique appropriée pour aider le processus de prise de décision concernant la sélection de modèles économiques viables pour l'ensemble des acteurs des réseaux de valeur alternatifs.

Chapitre 5. Proposition d'un cadre méthodologique pour la conception orientée vers les risques des offres Smart PSS : sPS^{2}Risk Framework.

Afin de répondre aux questions de recherche formulées dans le Chapitre 1, un cadre de conception pour les offres Smart PSS a été développé. Ce cadre méthodologique de conception en boucle fermée a été nommé : sPS^{2}Risk Framework. Il est constitué d'une étape préliminaire de contextualisation stratégique et cinq blocs méthodologiques. La mise en œuvre du sPS^{2}Risk Framework est soutenue par deux outils informatiques nommés « le sPS^{2}Modeller » et « le sPS^{2}Simulator » lesquels sont décrits dans le Chapitre 6.

Dans notre proposition, nous suggérons d'appliquer une étape préliminaire avant de mettre en œuvre le sPS^{2}Risk Framework. Les tâches de cette étape préliminaire visent à : (i) définir le segment client ciblé par les efforts de servicisation, (ii) cartographier les acteurs clés de la chaîne de valeur actuelle du manufacturier, et (iii) identifier les facteurs internes et externes favorables et défavorables par rapport aux efforts de servicisation numérique. Le sPS^{2}Risk Framework est composé de deux boucles nommées 'boucle de conception itérative' et 'boucle de validation itérative'. La première boucle comprend les blocs méthodologiques A, B et C tant que la deuxième boucle comprend les blocs méthodologiques restants.

Le bloc méthodologique A est nommé « Capture des attentes de valeur des parties prenantes clés ». L'objectif final de ce bloc est de lister les principaux besoins des parties prenantes qui devront être satisfaits par la solution Smart PSS. Pour ce faire, ce bloc propose d'utiliser des outils de la méthodologie connu sous le nom de *Design Thinking* (Lewrick et al., 2019) pour capturer et identifier des besoins auprès des parties prenantes, les prioriser, et les synthétiser sous la forme d'une question servant à guider

l'application du bloc méthodologique B, lui-même nommé « Prototypage du concept de valeur générale ».

Dans le bloc méthodologique B, la technique *brainstorming* (Lewrick et al., 2020) est appliquée pour définir le contenu de la proposition de valeur Smart PSS qui répondra aux besoins de parties prenantes clés. Ensuite, les éléments de cette proposition de valeur (i.e., les parties physiques et intangibles de la solution Smart PSS, et la demande associé) sont prototypés dans l'outil « le sPS²Modeller ». Par la suite, les offres de valeur alternatives pour commercialiser la proposition de valeur sont prototypées également sur « le sPS²Modeller ». La dernière tâche de ce bloc méthodologique consiste à animer un examen des risques, dans lequel les membres de l'équipe de conception identifient des risques d'innovation, évaluent leur impact, et proposent des mesures pour mitiger ces risques identifiés. A cet égard, si l'équipe de conception détermine que les risques identifiés sont gérables le troisième bloc méthodologique C est appliqué.

Le bloc méthodologique C est nommé « Spécification détaillée du concept de valeur». Ce bloc vise à configurer les possibilités de réseaux de valeur alternatifs pouvant délivrer la proposition de valeur Smart PSS aux clients. Dans ce but, les orientations proposées par Kage et al. (2016) pour la conception de réseaux de valeur sont adoptés dans ce bloc-ci. L'outil sPS²Modeller est employé pour prototyper les éléments nécessaires pour définir les configurations alternatives des réseaux de valeur ; par exemple, les acteurs impliqués, les indicateurs de performance exprimant les attentes de valeur des acteurs, entre autres. Ces prototypes sont vérifiés et validés avant l'animation d'un autre examen de risques. Les buts de cet examen sont de contrôler les risques identifiés dans le bloc méthodologique B, et d'évaluer de nouveaux risques identifiés grâce à la mise en œuvre du bloc méthodologique C.

Dans le cas où le niveau de risque est considéré acceptable, le quatrième bloc méthodologique D, nommé « Simulation et aide à la décision appliquées aux scénarios de réseaux de valeur Smart PSS ». Le but de ce bloc est d'évaluer la performance économique des réseaux de valeur alternatifs Smart PSS. Cette évaluation économique vise à assister le processus d'aide à la décision concernant la sélection des réseaux de valeur les plus financièrement viables pour l'ensemble des acteurs impliqués. A cette fin, les prototypes élaborés dans les blocs méthodologiques précédents sont utilisés pour formaliser les modèles économiques qui sont simulés dans les tâches ultérieures de ce bloc méthodologique. Par la suite, la plateforme de simulation de performance économique adaptée au Smart PSS est créée. Dans cette thèse, nous avons développé l'outil nommé sPS²Simulator pour simuler la profitabilité des réseaux de valeur configurés pour l'étude de cas présentée dans le Chapitre 7. Cet outil est utilisé pour effectuer l'analyse de viabilité économique des configurations de réseaux de valeur alternatifs et l'évaluation quantitative de l'incertitude des modèles économiques associés à ces réseaux. A partir des résultats de cette analyse économique, les concepteurs définissent des stratégies de mitigation de risques de viabilité.

Finalement, basé sur les résultats du bloc méthodologique D, le dernier bloc méthodologique E est appliqué. Ce dernier bloc méthodologique est nommé « Développement et prototypage expérimental de la solution Smart PSS ». Le but de ce bloc méthodologique est de créer un prototype physique de la

solution Smart PSS pouvant être testé dans un contexte réel. Pour cette raison, la création d'un Produit Minimum Viable (MVP) et d'un Écosystème Minimum Viable (MVE) sont nécessaires. Les tests de ce prototype expérimental avec des utilisateurs permettent de capturer un retour important pour affiner la proposition de valeur et les réseaux de valeur Smart PSS. L'animation d'un autre examen des risques est suggérée par notre cadre méthodologique de conception dans le but de discuter les risques identifiés et les stratégies de mitigation mises en œuvre. Cet examen des risques aide les décideurs industriels à prendre des décisions éclairées concernant le lancement dans le marché de l'offre Smart PSS.

Chapitre 6. Un ensemble d'outils de modélisation et de simulation pour soutenir la mise en œuvre du cadre méthodologique de conception sPS²Risk Framework.

Ce chapitre décrit les outils utilisés pour mettre en œuvre le cadre méthodologique proposé dans un contexte réel de conception. D'un côté, le sPS²Risk Framework emploie des outils génériques des domaines du design et du management de projets, tels que des outils du *Design Thinking* comme le *récit utilisateur*. D'un autre côté, dans le cadre de cette thèse, nous avons développé deux outils informatiques adaptés à la conception d'offres Smart PSS dans l'industrie des appareils de chauffage résidentiels. Nous avons nommé ces outils le sPS²Modeller et le sPS²Simulator.

Le sPS²Modeller est un outil de modélisation conceptuel permettant de générer des prototypes digitaux de différents éléments du système associé à l'offre Smart PSS. Les principaux objectifs de cet outil de modélisation sont de servir d'outil de visualisation dans le processus de conception et d'être un référentiel de connaissances. La base pour le développement de cet outil a été le métamodèle proposé par Medini et Boucher (2019), lequel a été enrichi en considérant les particularités du processus de conception des offres Smart PSS. Le métamodèle résultant a été mis en œuvre sur la plateforme ADOxx pour créer le logiciel de modélisation sPS²Modeller. Le logiciel résultant est constitué de dix vues de modélisation générant différents modèles conceptuels. Ces vues de modélisation sont nommées : écosystème, produit, service, demande, offre, activité, organisation, performance, scenario et réseau de valeur.

Cet outil est utilisé dans la mise en œuvre des blocs méthodologiques A, B et C pour créer des modèles conceptuels concernant surtout la proposition de valeur et les réseaux de valeur Smart PSS. Ces modèles conceptuels facilitent la communication entre les membres de l'équipe de conception et aussi avec les parties prenantes externes. Également, ces modèles conceptuels servent de support cognitif pour faciliter l'identification des risques d'innovation. Les modèles conceptuels créés sur le sPS²Modeller et les informations stockés dans ces modèles sont la base pour le développement de l'outil sPS²Simulator.

Le sPS²Simulator est un outil de simulation quantitative permettant de prédire la performance économique des réseaux de valeur alternatifs pour commercialiser l'offre Smart PSS. Ces réseaux de valeur sont représentés dans la vue 'réseau de valeur' du sPS²Modeller. La performance économique est évaluée en termes d'indicateurs de performance définis dans la vue 'performance' du sPS²Modeller. Le

sPS^{2}Simulator a été développé pour l'étude de cas développée dans le Chapitre 7. Les informations générées pendant l'application des trois premiers blocs méthodologiques à l'étude de cas ont été transformées en pseudocodes pour guider le développement de cet outil de simulation. Ces pseudocodes ont permis la construction des algorithmes, lesquels ont été transformés en codes informatiques sur un environnement de développement. Pour l'étude de cas, l'environnement de développement informatique utilisé a été Visual Basic. Ainsi, une maquette de simulateur de performance économique adapté à l'étude de cas a été créée.

Le sPS^{2}Simulator permet d'estimer des indicateurs de performance calculés par année pour l'ensemble des acteurs clés des réseaux de valeur. Parmi les indicateurs estimés nous trouvons le chiffre d'affaires, les coûts totaux, les profits bruts, aussi d'autres types des indicateurs tels que le nombre d'interventions de maintenance et le nombre de pièces détachées, entre autres. Ces estimations ne sont pas déterministes mais elles prennent en compte la variabilité de certains paramètres d'entrée représentant des facteurs dynamiques évoqués par Phumbua et Tjahjono (2012). Pour ce faire, des paramètres d'entrée tels que le volume du marché en termes d'abonnements vendus par mois et la probabilité de défaillance de l'appareil de chauffage sont simulés avec des variations selon un plan d'expérience, dans chaque itération de la simulation. Le nombre d'itérations est fixé par l'utilisateur de l'outil. Le sPS^{2}Simulator a été construit pour estimer les indicateurs de performances associés aux réseaux de valeur alternatifs de l'étude de cas. Ces réseaux alternatifs représentent scenarios combinant des modèles économiques pour commercialiser l'offre (e.g., orientée vers le produit, orientée vers l'usage) et des bouquets de services inclus dans l'offre (PSS ou Smart PSS).

L'outil de simulation est utilisé dans l'application du bloc méthodologique D, plus spécifiquement dans la mise en œuvre de la tâche D4.3 concernant l'analyse économique et l'évaluation de l'incertitude selon les paramètres d'entrée des modèles économiques. Le sPS^{2}Risk Framework permet de réaliser l'analyse de scénarios et l'analyse de sensibilité inclus dans cette tâche. Les résultats de ces analyses sont utilisés pour tracer le tableau de bord visant à comparer la performance économique des réseaux de valeur alternatifs. A partir de ces résultats, les managers peuvent concevoir des stratégies de mitigation pour contrôler les risques de viabilité financière. Ce tableau de bord a pour objectifs d'assister les managers dans le processus de prise de décision concernant le lancement de l'offre Smart PSS sur le marché. L'application des outils dans l'étude de cas est décrite dans le Chapitre 7.

Chapitre 7. Application du cadre méthodologique sPS²Risk Framework pour concevoir des offres Smart PSS dans le domaine du chauffage résidentiel.

La validation de l'applicabilité du cadre méthodologique de conception détaillé dans le Chapitre 5 et des outils d'appui décrits dans le Chapitre 6 a été effectuée à travers d'une étude de cas. Elm.leblanc est l'entreprise focale de cette étude de cas. L'application pas à pas du sPS²Risk Framework est décrite dans ce chapitre. Dans l'étape de contextualisation stratégique, le segment client choisi pour être ciblé par les efforts de servicisation numérique est le marché résidentiel individuel des particuliers.

Les tâches du bloc méthodologique A ont été effectuées avec le support d'un cabinet de conseil. Cette société a capturé les besoins des propriétaires particuliers de logements concernant leurs préférences au moment de remplacer leurs appareils de chauffage et leurs habitudes pour chauffer leurs logements. De plus, les attentes de valeur des installateurs indépendants ont été capturées et analysées. A partir de ces informations, nous avons déterminé que les principaux besoins des propriétaires particuliers en tant que clients concernent l'abordabilité et les coûts de fonctionnements des appareils de chauffage. Les attentes de valeur identifiées pour les installateurs concernent principalement la rentabilité de leur modèle d'affaire.

Lors de l'application du deuxième bloc méthodologique, une séance de brainstorming a été effectuée pour définir la proposition de valeur répondant aux besoins identifiés dans l'application du premier bloc méthodologique. A la suite de cette séance de brainstorming, un abonnement mensuel dans lequel le client paie pour la disponibilité et les coûts de maintenance de l'appareil de chauffage a été proposé pour répondre à ces besoins. Cet abonnement a été conçu pour être commercialisé sur trois modèles économiques alternatifs, évoqués sous les noms de (i) 'financement et maintenance' (un modèle orienté vers le produit), (ii) leasing et (iii) location (les deux derniers modèles sont orientés vers l'usage).

Deux bouquets de services pouvant être inclus dans ces abonnements ont été définis : le bouquet PSS et le bouquet Smart PSS. La différence entre les deux bouquets de services est que le second inclut le service numérique de suivi à distance de l'appareil de chauffage. Ce service de suivi à distance permet d'identifier les défaillances de l'appareil de chauffage à distance et la pièce détachée requise et alerter les dépanneurs et clients sur la défaillance. Également, ce service permet au client de suivre sa consommation d'énergie. La proposition de valeur et l'offre de valeur ont été modélisés sur le sPS²Modeller. Les chaudières à gaz et les pompes à chaleur ont été inclus comme produits dans les abonnements. Plusieurs risques d'innovation et des mesures pour les mitiger ont été identifiés dans l'application de ce bloc méthodologique. Ces descriptions des risques et des mesures ont été enregistrés sur le registre des risques, accessible sur le sPS²Modeller.

Dans l'application du troisième bloc méthodologique, les réseaux de valeur nécessaires pour fournir les abonnements susceptibles d'être commercialisés ont été configurés. Les prototypes de ces réseaux de valeur ont été créés sur le sPS²Modeller. Dans ces modèles, plusieurs aspects sont représentés, notamment : (i) les acteurs nécessaires pour fournir l'offre et leurs rôles, (ii) les indicateurs de

performance exprimant les attentes de valeur des acteurs, (iii) les différents scénarios combinant des modèles économiques et des bouquets de services, et (iv) les flux de valeur entre les acteurs dans ces scénarios. A la suite de ces modélisations, quatre acteurs ont été considérés comme clés dans les scénarios alternatifs : elm.leblanc en tant que fabricant et service après-vente, le fournisseur de l'abonnement (une société externe), le réseau d'installateurs et le client. Sur la base de ces modèles, des risques d'innovation additionnels ont été identifiés avec leurs respectives mesures de contrôle. Par conséquent, le registre des risques a été mis à jour.

A partir des modèles des scénarios alternatifs des réseaux de valeur et des informations enregistrées dans ces modèles, l'outil de simulation de performance économique sPS^{2}Simulator a été développé. Cet outil a été utilisé pour estimer les profits associés aux réseaux de valeur alternatifs configurés dans le bloc méthodologique C. Plus précisément, l'outil a permis d'adresser trois questionnements clés. Pour aborder ces questionnements, trois groupes de paramètres d'entrée ont été définis, lesquels nous avons nommés pessimiste, réaliste, et optimiste.

D'abord, l'outil a permis d'estimer la valeur ajoutée du bouquet de services Smart PSS pour le service après-vente (elm.leblanc) qui fournit la maintenance et le service numérique, par rapport au bouquet PSS (le service numérique n'est pas inclus). Deuxièmement, la valeur monétaire générée par les scénarios alternatifs combinant les modèles économiques et les bouquets de services a été estimée puis comparée, en considérant la perspective d'elm.leblanc. Pour rappel, elm.leblanc génère des revenus à partir de la vente des abonnements grâce à la vente des appareils de chauffage inclus dans l'abonnement et aux activités de maintenance de l'appareil couverts par l'abonnement. Enfin, la valeur monétaire générée par les scénarios est simulée avec les trois groupes de paramètres définis. Les simulations sont effectuées avec ces groupes de paramètres afin de tester la résilience des scénarios face à la variation simultanée d'un ensemble de paramètres d'entrée. Ces simulations sont réalisées en considérant les perspectives de l'ensemble des acteurs clés.

Les résultats de ces simulations sont utilisés pour construire un tableau de bord servant d'appui au processus d'aide à la décision concernant la sélection des réseaux de valeur à mettre en place sur le marché. Ce tableau de bord est aussi utilisé pour aider à la conception des stratégies de mitigation pour les risques de viabilité financière associés à la fourniture des bouquets de services. Nous avons formulé des recommandations pour elm.leblanc à partir de ces résultats. Finalement, concernant le dernier bloc méthodologique nous avons utilisé le retour du développement et des tests du service de service à distance 'Optibox', lequel est commercialisé par elm.leblanc dans le marché B2B. De plus, nous avons aussi considéré le retour de la commercialisation des abonnements vendus par le groupe Bosch en Allemagne depuis septembre 2020. Ces abonnements sont similaires à ceux de notre étude de cas. Finalement, les professionnels d'elm.leblanc impliqués dans cette étude de cas ont validé l'efficacité de l'application du sPS^{2}Risk Framework et des outils informatiques d'appui (le sPS^{2}Modeller et le sPS^{2}Simulator).

Chapitre 8. Conclusions et perspectives.

Cette thèse contribue à la littérature dans le domaine de la conception axée sur la valeur des offres Smart PSS en introduisant un nouveau cadre méthodologique de conception. Notre proposition intègre deux aspects souvent non traités dans la littérature du Smart PSS. Le premier aspect concerne les dimensions du processus d'innovation du modèle d'affaires (Gassmann et al., 2014), à savoir, le segment client, la proposition de valeur, le réseau de valeur, et le mécanisme de génération des profits. Ces dimensions sont souvent abordées séparément dans la littérature existante (Alix et Zacharewicz, 2021). A ce propos, l'estimation de profits générés à partir de la vente des offres Smart PSS est la dimension le moins abordée dans la littérature (Parida et al., 2019). Le deuxième aspect concerne le management des risques d'innovation (Osterwalder et al., 2020). Cet aspect n'a pas été traité dans la littérature du Smart PSS malgré le rôle de l'émergence de ce type des risques dans l'occurrence du paradoxe de la numérisation. Ce paradoxe décrit la situation dans laquelle la société offrant la solution Smart PSS sur le marché n'atteint pas les objectifs de rentabilité attendus. Le management des risques d'innovation est intégré dans le sPS^{2}Risk Framework. D'un côté, il est incorporé en utilisant l'approche qualitative standardisée de management des risques dans trois blocs méthodologiques. D'un autre côté, nous avons incorporé l'approche quantitative d'évaluation des risques dans le bloc méthodologique D, adressant l'estimation de la valeur monétaire générée par la commercialisation de l'offre Smart PSS.

La thèse a également contribué à la littérature avec le développement et la validation de deux outils de support à la conception des offres Smart PSS. Le premier outil consiste en un logiciel de modélisation qualitative, lequel implémente l'approche de prototypage conceptuel du sPS^{2}Risk Framework. Les modèles créés par cet outil répondent aux besoins d'agilité dans la conception des offres Smart PSS. De plus, ces modèles servent de support cognitif pour faciliter l'identification de risques d'innovation par l'équipe de concepteurs. La revue de littérature présentée dans le Chapitre 6 sur les outils de prototypage conceptuel proposés dans le contexte de conception des offres Smart PSS nous a montré que ce type d'outils était jusqu'à présent limité.

Le deuxième outil de support concerne un simulateur de performance économique des réseaux de valeur pour fournir la proposition de valeur Smart PSS. Cet outil permet d'estimer et de comparer la profitabilité associée à la vente de l'offre Smart PSS en considérant un ensemble de configurations alternatives des réseaux de valeur. La revue de la littérature présentée dans le Chapitre 6 nous a permis de montrer que les outils disponibles pour évaluer la viabilité financière des offres Smart PSS en considérant une perspective multi-acteurs sont insuffisants. Ainsi, cette thèse contribue à la littérature en ce qui concerne le management des risques de viabilité économique associés à la mise en place des offres Smart PSS sur le marché. De plus, le sPS^{2}Simulator permet de comparer la performance économique des offres PSS et Smart PSS, une fonctionnalité qui n'a pas été signalée dans d'autres outils.

Le déroulement de cette thèse a présenté des limitations. En ce qui concerne le processus de recherche, la proposition conceptuelle a été validée en appliquant seulement une étude de cas. Afin de valider

l'applicabilité intersectorielle de la proposition conceptuelle, il est nécessaire de la valider en l'appliquant dans d'autres études de cas. De plus, l'efficacité de la proposition a été testée dans les activités d'elm.leblanc. Néanmoins, la proposition n'a pas été intégrée ni standardisée dans les routines de conception de ce fabricant compte tenu que cette tâche n'était pas dans la portée de cette thèse.

Enfin, nous avons trouvé des limitations dans l'évaluation économique réalisée dans le cadre de cette thèse. Ces limitations concernent l'exactitude des paramètres d'entrée, lesquels pour raisons de confidentialité ont été extraits des sources publiques. Malgré le caractère incertain de plusieurs paramètres d'entrée, des lois de probabilité n'ont pas été affectées à ces paramètres en raison de l'absence de données historiques. Par ailleurs, l'évaluation économique a considéré un système industriel à capacité infinie, compte tenu de l'indisponibilité des données pouvant être plus représentatifs de la réalité ; par exemple, la distribution géographique du nombre de ressources humaines.

Certains aspects n'ont pas été abordés dans cette thèse lesquels ouvrent la possibilité d'être traités par de nouveaux travaux de recherche. D'abord, en ce qui concerne l'évaluation de la performance des offres Smart PSS, seulement la dimension économique a été évaluée. Cependant, la génération de la valeur durable est un thème de plus en plus crucial dans l'étape de conception des offres Smart PSS. Par conséquent, les dimensions environnementale et sociale devraient aussi évaluées dans l'étape de conception. Dans cette perspective, le processus de décision devient multi-acteurs et multicritères. Ainsi, la sélection du réseau ou des réseaux de valeur générant le plus de valeur durable (et non plus uniquement économique) devient la décision à prendre par les concepteurs. A cet égard, le développement d'un outil informatique pouvant simuler l'ensemble de dimensions de la durabilité pour les offres Smart PSS est une piste de recherche intéressante.

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Appendices

Appendix I. Application of the methodological block C: Specification of the detailed value concept (case study).

Appendix I.1. Recap of actors required in the value network scenarios.

Actor involved	Deliverable	Economic model	Service package
Control manufacturer	Thermostat, connectivity hardware	All three economic model scenarios	Both PSS and Smart PSS
Financing provider (bank)	Customer credit	Financing and maintenance subscription	Both PSS and Smart PSS
Insurance company	Credit default insurance	Financing and maintenance subscription	Both PSS and Smart PSS
	Third-party liability insurance	Leasing and rental	Both PSS and Smart PSS
Data analytics provider	Breakdown alerting	All three economic model scenarios	Smart PSS
Service provider	'Heating-appliance-as-a-service' subscription	All three economic model scenarios	Both PSS and Smart PSS
Data transmission provider	Transmission of data collected from installed appliances	All three economic model scenarios	Smart PSS
Disposal and recycling companies	Recycling and final disposal of the uninstalled appliance.	All three economic model scenarios	Both PSS and Smart PSS

Main cost activities and revenue sources for the key actors.

Actor	Main cost activities	Revenue sources
Heating appliance manufacturer (A1) (elm.leblanc)	- Design, manufacturing, and distribution of the heating appliance.	- Sale of the heating appliance to wholesalers.
Packaged solution provider (A2)	- Customer acquisition. - Purchase of the heating appliance from the installer. - Heating appliance installation fees at the customer's home. -Monthly billing.	- Customer payment for the packaged solution (recurrent revenue).
Installer network (A3) (elm.leblanc's partnered installers)	- Labour and travel cost for pre-installation and installation visits, or uninstallation (depending on the economic model). - Disposal of replaced heating appliance. - Purchase of the heating appliance and required materials from the wholesaler.	- Sale of the heating appliance to the packaged solution provider. - Installation service fees.
After-sales service company (A4) (elm.leblanc)	- Labour and travel costs involved in the maintenance operations. - Spare part purchase. - Digital service delivery.	-Sale of the maintenance contract to the customer or payment for each maintenance operation.
Customer (A5)	- Recurrent payment for the packaged solution.	- Potential savings compared to the traditional heating system purchase.

Appendix I.2. Assumptions made for value network modelling.

(i)   In the product-oriented economic model (M1), the after-sales service company (A4) sells a maintenance contract to the customer (the private homeowner, A5) via a third party (A2). This third party makes a margin on the maintenance contract. The average price of this maintenance contract in the French market is 10,3€ per month (123€ per year). Spare parts needed that are not covered by the manufacturer's warranty are charged to the customer.

(ii)   In the use-oriented economic models (M2 and M3), the heating appliance owner, the packaged solution provider (A2), pays the after-sales service company (A4) for each maintenance operation (annual routine maintenance, repair operations) each time that an intervention takes place, including the spare parts needed, if these are not covered by the manufacturer's warranty.

(iii)   In M1, after the packaged contract expiration, the customer is given the possibility to renew the contract as a classical maintenance contract (pure service). If the customer first subscribed to a PSS contract, at the end of this contract they can switch to a classical maintenance contract that includes the remote diagnostic service as an add-on.

(iv)   The manufacturer (A1) is the spare part supplier for the after-sales service company (A4).

(v)   A Smart PSS contract's implementation is reflected in the corrective maintenance costs for A4, as the number of visits at customers' homes and the overall repair time are expected to

decrease. In M1, no additional monetary benefits are implied for the customer, as the labour and travel cost of corrective maintenance operations are included in the maintenance contract scope. The customer benefit is mainly related to peace of mind. Contrarily, in M2 and M3, A2 as the heating appliance owner is expected to lower its maintenance operational costs. As a reminder, in these two economic model scenarios, A2 pays A4 for each maintenance operation, either routine maintenance or corrective maintenance operation.

(vi)   The product distribution channel is the same in the three assessed economic model scenarios (the installer purchases the heating system at a wholesalers').

(vii)   The technical and finance risks are distributed as follows:

Risk usually born by the customer	Finance and maintenance contract (M1)	Leasing (M2)	Rental (M3)
Financial	- A2 serves as an intermediary between the finance provider (the firm that grants the credit) and the customer. - In case of customer default, the credit is backed by an insurance policy included in the packaged solution.	A2 purchases the heating systems and remains owner of the appliance. This purchase is financed by A2's internal funding. The heating systems leased or rented to customers become assets of the packaged solution provider (A2). Hence, A2 bears the risk of customer default.	
Technical	- The after-sales service (A4) covers the labour and travel costs in the scope of the contract they sell to the customer (A5). - The manufacturer (A1) covers the cost of certain spare parts in the warranty, during a fixed period. - If the spare parts are not included in the warranty, the customer must bear their cost.	A2, as owner of the heating appliances must pay the after-sales service (A4) for the mandatory routine maintenance, the repairs, and spare parts that need to be replaced. Hence, the entire technical risk is undertaken by the packaged solution provider (A2).	

(viii)   Heat pumps were not included in M3, as rental offerings of these appliances were not found in the existing offerings in the European market. This situation can be explained due to the higher cost of installing a heat pump compared to a gas boiler, and the complexities involved in the installation and uninstallation processes.

(ix)   In M1, the package solution provider can claim government subsidies on behalf of the client. The subsidy amount depends on the homeowner's revenues. The difference between the price of the heating appliance and its installation and the subsidy, is the amount to be paid through the credit claim with the finance provider. Therefore, the price of the monthly bill paid by the customer varies depending on two factors: the subsidy amount the customer is entitled to, and the type of product. For the latter, this depends on whether it is gas boiler or heat pump, and the dwelling's characteristics (surface, number of tenants, hot water production needs).

(x)   According to the current regulations, in M2 and M3, the packaged solution provider (A2) and heating appliance owner cannot obtain government subsidies to finance the purchase of heating systems to install them at the customers' homes. Consequently, the monthly bill price depends exclusively on the product technology and dwelling's characteristics

addressed by the heating appliance technical features (e.g., number of domestic hot water connections), and not on the customer's household income.

For the Smart PSS contract, in addition, to the conditions abovementioned, the assumptions made are:

(i)   In M1, the customer (A5) pays a monthly additional fee to the after-sales company (A4) via the packaged solution provider (A2). In the French market, competitors charge a fee of 6€ per month for the remote diagnostic service. A hypothetical remote diagnostic service for heat pumps was also included.

(ii)   In M2 and M3, as the packaged solution provider (A2) owns the heating appliances, the assumption was that the remote diagnostic service was charged annually in advance to A2. This assumption was based on the existing remote diagnostic contracts with social housing providers that are charged as described above. In other words, each time a Smart PSS contract is sold to a private homeowner, A2 pays in advance an annual fee to A4.

(iii)   When subscribing to a Smart PSS contract, A2 expects a preferential rate for the repair operations. Therefore, in a Smart PSS contract, the markup for the A4 on the repair services are lower compared to the repairs carried out under a PSS contract.

(iv)   Under the current regulations, the mandatory routine maintenance must be carried out every twelve months, in both PSS and Smart PSS contracts. Hence, no cost reductions concerning preventive maintenance are considered.

(v)   The hardware (communication module) required for the remote diagnostic service is purchased by the installer at a wholesaler. The installer makes a margin on the sale of this hardware to the heating system owner. In M1, the customer (A5) owns the hardware, while in M2 and M3 the packaged solution provider (A2) owns this hardware.
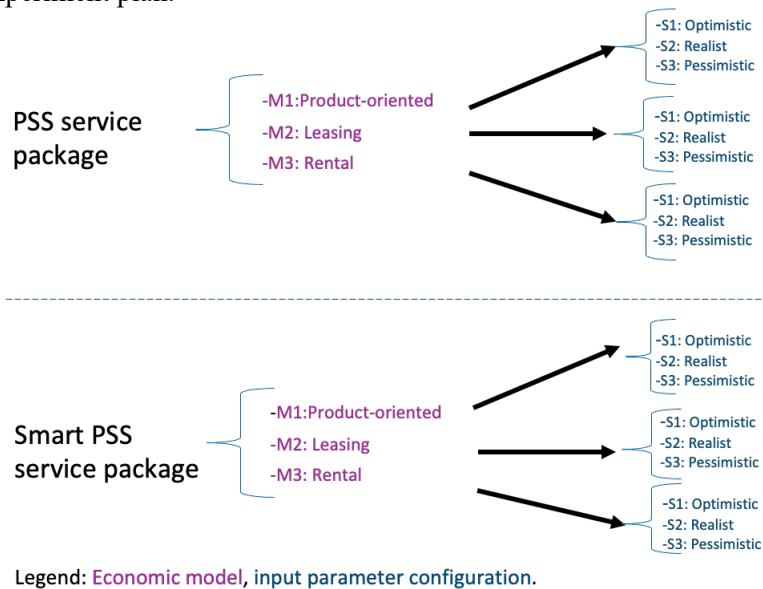
Appendix II. Application of the methodological block D: Simulation and decision-making applied to the Smart PSS delivery scenarios.

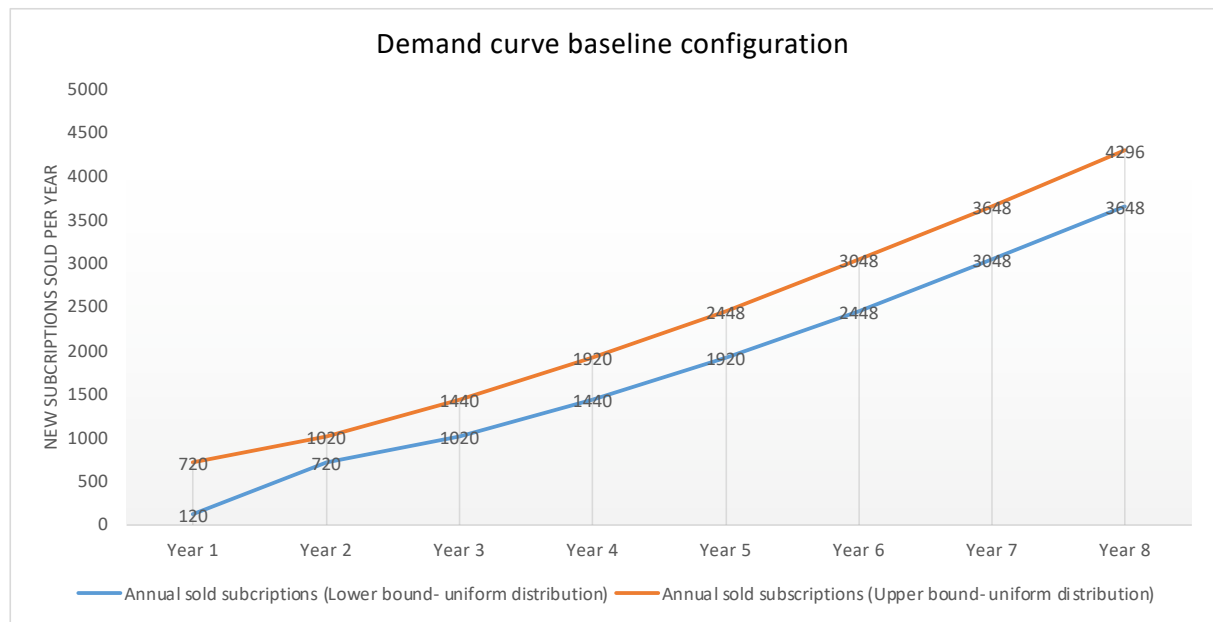Appendix II.1: Input parameter configurations.
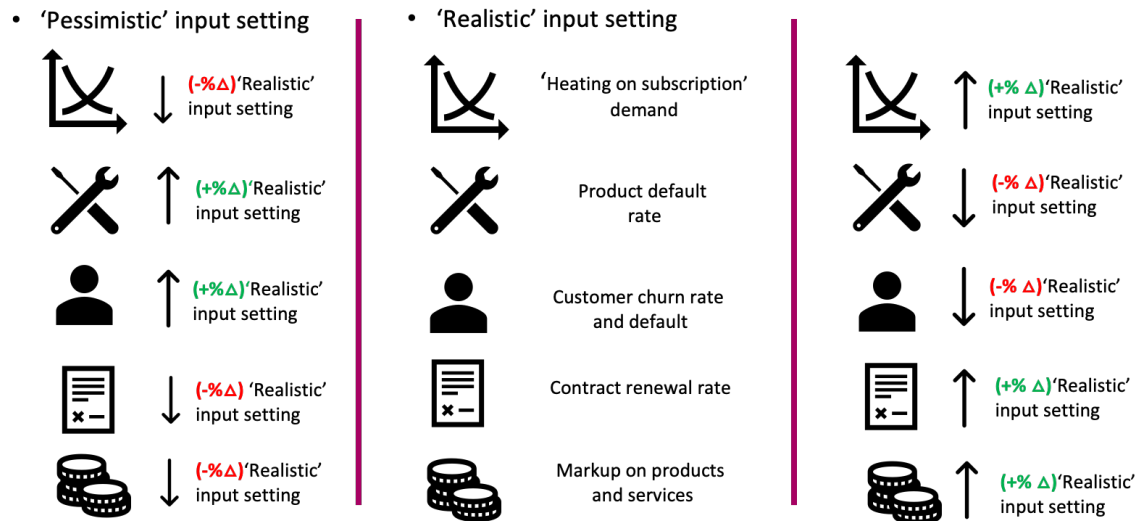
Appendix II.2: Experiment plan.

Appendix II.3: Demand curve used in the sensitivity analysis

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A RISK-ORIENTED FRAMEWORK FOR SMART PSS DESIGN, CONSIDERING VALUE NETWORK AND ECONOMIC MODEL CONFIGURATION

Speciality : Industrial engineering

Keywords : Smart PSS design, digital servitization, Smart PSS value network, Smart PSS prototyping, Smart PSS economic performance simulation.

Abstract :

Multiple manufacturers have launched service-based offerings to gain a competitive advantage. These offers are all-inclusive solutions enabled by digital platforms that bundle products, and physical and digital services. The commercialization of these offers known as Smart PSS involves new sources of risk for the financial sustainability of the delivery network actors. This thesis, carried out with the company elm.leblanc, addresses the issue of anticipating and controlling innovation risks during the early design stage of product-service offers integrating digital services.

The proposal resulting from this thesis addresses this risk anticipation problem by proposing a methodological design framework for Smart PSS offerings. This proposal called sPS²Risk, addresses a value-oriented perspective to guide the design process and considers the four dimensions of the Business Model Innovation process. The sPS²Risk framework is based on three principles: iterative and incremental development, creating different types of prototyping, and managing innovation risks. The proposed framework was instantiated on a case study in the field of residential heating to validate its effectiveness. In order to facilitate the application of the methodological framework, two computer tools were developed and customized to the case study: a conceptual modelling tool and a multi-actor economic performance simulator.

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MÉTHODE DE CONCEPTION INTEGRÉE DE SYSTÈMES PRODUITS-SERVICES AVEC CONFIGURATION DES CHAÎNES DE CRÉATION DE VALEUR ET DE LEURS MODÈLES ÉCONOMIQUES.

Spécialité: Génie industriel

Mots clefs : Smart PSS design, servicisation numérique, prototypage Smart PSS, réseau de valeur Smart PSS, simulation performance économique.

Résumé :

De nombreux fabricants ont lancé des offres basées sur les services pour obtenir un avantage concurrentiel. Ces offres sont des solutions tout compris rendues possibles par des plateformes numériques regroupant des produits et des services physiques et numériques. La commercialisation de ces offres connues sous le nom 'Smart PSS' implique de nouvelles sources de risque pour la pérennité financière des acteurs du réseau de valeur. Cette thèse, réalisée avec la société elm.leblanc, aborde la problématique de l'anticipation et de la maîtrise des risques d'innovation lors de la phase de conception d'offres produits-services intégrant des services numériques.

La proposition issue de cette thèse répond à cette problématique d'anticipation des risques en proposant un cadre méthodologique de conception des offres Smart PSS. Cette proposition, appelée sPS²Risk, aborde une perspective axée sur la valeur pour guider le processus de conception et considère les quatre dimensions du processus d'innovation du modèle d'affaires. Le cadre méthodologique sPS²Risk repose sur trois principes : le développement itératif et incrémental, la création de différents types de prototypage et la gestion des risques d'innovation. Le cadre proposé a été instancié sur une étude de cas dans le domaine du chauffage résidentiel pour valider son efficacité. Afin de faciliter l'application du cadre méthodologique, deux outils informatiques ont été développés et adaptés au cas d'étude : un outil de modélisation conceptuelle et un simulateur de performance économique multi-acteurs.