Designing a Value Proposition for the Home Energy Management System: Aiming to Enhance Residential Consumer Adoption

UNIVERSITY OF TWENTE.

Keywords: Home Energy Management System, Value Proposition, HEMS, Benefits, VPC, Enhancing Residential Consumer Adoption, Utility, Design Science Research

STUDY PROGRAM
Master of Science in Business Administration
Faculty of Behavioural, Management and Social Sciences

EXAMINATION COMMITTEE
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Abstract

The ongoing process of sustainable advancements within electricity grids heralds a new phase of the global energy transition. Moreover, a phase defined by uncontrolled electricity generation from renewable energy sources (RES), the incorporation of energy storage and demand side management (DSM) techniques. Given the potential of the Home Energy Management System (HEMS) to assist utilities, grid operators and governments in DSM and national grid support, these stakeholders are advocating for large-scale HEMS adoption by residential consumers worldwide. However, despite the fact that available HEMSs align with the technological industry standards and are capable of providing individual benefits to its end-users, adoption among these residential consumers is falling short of the global expectations. Therefore, the objective of this research was to design a value proposition for the HEMS aimed to enhance residential consumer adoption. An initial Value Proposition Canvas was designed through the lens of a utility, by aligning their envisioned Value (Proposition) Map with the identified Residential Consumer Profile of this study. This profile was constructed on the basis of data acquired from four qualitative focus group interview sessions with residential consumers. Subsequently, four validation interviews with HEMS experts from were conducted, to assess the alignment within the initial HEMS Value Proposition Canvas and gather additional expert insights regarding the enhancement of residential consumer HEMS adoption. The key findings of this study identified four underlying adoption domains. In addition, five core HEMS values for residential consumers were determined. Incorporating these findings alongside principles from the Innovation-Decision Process model and Technology Acceptance Model, a final Value Proposition Canvas design was presented for the HEMS. Therefore, this research provides an academic contribution by underscoring the manner in which residential consumer adoption of the HEMS can potentially be enhanced. Moreover, it offers a guideline for stakeholders that desire to implement sustainable energy solutions and it marks a significant stride within the discourse on global energy transition. However, due to confidentiality, the complete version of this research paper will be made publicly available from the 1st of January 2025. Below, a public summary of the research will therefore be provided.

1. Introduction

Despite today's global familiarity with the energy transition, the matter remains a dominant topic with ongoing advancements. Furthermore, awareness regarding the consequences caused by fossil fuel implications spurred rapid integration of renewable energy sources (RES) within energy grids all over the world. According to Hossein Motlagh et al. (2020), the Internet of Things (IoT) has become critical related to the optimalization of modern energy systems, since IoT-based technologies can be applied within these systems to improve their efficiency, increase the share of RES, and thus reduce environmental impacts. Nowadays, according to Lin et al. (2017), the IoT is especially utilised effectively within the smart grid domain. While originally introduced to replace traditional energy grids, through the provision of reliable and efficient energy services towards integrated residential consumers, smart grids have since evolved to become the global standard within the energy sector. This emergence was primarily caused by the rise of smart meters, together with underlying and bidirectional communication networks, fostering interactions between residential consumers and utilities. Moreover, since these smart meters allow utilities to monitor various aspects of residential energy utilisation, such as consumption (patterns) and electricity generation from private solar panels, residential consumers are digitally provided with valuable insights related to their costs. In addition, home area networks (HAN) parallelly transformed the electricity utilisation patterns during this period, labelled as the smart grid era by Zhou et al. (2016). Lastly, the upcoming trends of vehicle-to-grid (V2G) technologies as well as energy storage systems (ESS), combined with the extensive generated electricity loads of private RES, have reshaped the manner in which electricity is managed today. Namely, steering away from the centralized (national) energy grid infrastructures and shifting further towards decentralized cyber-physical energy systems. Elaborating further, RES- and ESS-integrated smart grids which incorporate demand side management (DSM), by utilising techniques such as short-term demand response (DR), to modify the residential electricity demand. This demand response enables residential consumers within smart grids to actively participate in the system's management of electricity, by modifying their consumption during peak periods, in exchange for beneficial time-based tariffs and additional personalized incentives. Therefore, according to Hui et al. (2020), IoT-based demand response techniques are widely considered as an effective approach for utilities in realizing long-term demand side management objectives within smart grids.

A theoretical concept that complements this decentralized smart grid approach exceptionally well and is therefore becoming increasingly indispensable on global scale, is the Home Energy Management System (HEMS). According to Shareef et al. (2018), the HEMS qualifies for demand side management within smart grids since it integrates an automated demand response tool, to efficiently manage the residential electricity demand within smart homes. Moreover, the HEMS optimizes consumption schedules by considering multiple factors, including costs, load profiles and end-user comfort. Since the HEMS receives tariff-related information form utilities upfront, the system is capable of purchasing lower-priced electricity for residential consumers during daily off-peak hours. Optionally, private RES (e.g., solar panels) and home batteries are utilised to support the optimal management of a residential consumer's smart home components during the remaining peak hours. Consequently, Shakeri et al. (2017) underlined the significance of residential consumer adoption of the HEMS within future smart grid electricity management, as the HEMS characteristics enable improved electricity management, finances, and reliability for both residential consumers as well as utilities. Therefore, the current value proposition for the HEMS offers residential consumers integration of the system within their (smart) homes, in exchange for individual benefits and the opportunity to contribute to the smart grid demand side management exerted by utilities. Given the potential of this mutual trade-off, various utilities around the world seek residential consumer adoption of the HEMS, in an attempt to achieve their demand side management objectives.

1.1 Problem identification and research motivation

As outlined above, HEMS utilisation within smart grids thus has the potential to yield multiple advantages for various stakeholders involved. Furthermore, according to Nizami et al. (2019), the HEMS can offer benefits to residential consumers while still maintaining their end-user comfort. Simultaneously, the integrated demand response tool is able to contribute to local voltage-violation-support, as well as direct load control of national electricity grids. However, in order to realise these mutual benefits, the active involvement and participation of residential consumers within smart grids is of pivotal importance for utilities and grid operators. Therefore, achieving widescale residential consumer adoption of the HEMS could arguably form the gateway to the establishment of an optimal incentive structure, in which benefits for (residential) consumers, utilities, grid operators, and governments are optimised. However, after an assessment of the HEMS market and the identification of several adoption barriers, Sanguinetti et al. (2018) concluded that precisely the residential consumer adoption of the HEMS is falling short of expectations within practical implementations of the system. Therefore, no established or documented optimal incentive structure is currently presented within the HEMS, demand side management and/ or smart grid literature, resulting in unrealised potential for stakeholders within the energy sector, as well as suboptimal functioning smart grids around the world.

Based on this, a significant knowledge gap was identified for this study, related to the residential consumer adoption of the HEMS. Specifically, this gap pertained to the lack of understanding regarding the integration and role of residential consumers within smart grids, through their utilisation of the HEMS. This knowledge gap did not solely obstruct the realization of demand side management and smart grid objectives for utilities but hindered the progress of additional important stakeholders within the energy sector as well, thereby impeded the next phase of the global energy transition. Motivated by these observations and recognizing the awaiting potential that widescale residential consumer adoption of the HEMS within modern energy systems may unlock, this research aimed to further explore this gap.

1.2 Central research question and treatment contribution

Reinforcing the above, the critical role of residential consumers regarding the adoption of smart home technologies (e.g., the HEMS) was strongly highlighted as Ringel et al. (2019) claim that governmental policymakers harbour aspirations to incentivize microeconomic actors towards harmonising their decisions with broader macroeconomic strategies. Through emphasis on the economic, environmental, and social end-user benefits at the microeconomic level, residential consumers might become advocates for energy efficiency out of enlightened self-interest. As such, this presents an appealing path for utilities to realise demand side management objectives through the HEMS. In addition, Kim et al. (2021) argued that the majority of previous HEMS-related research skewed towards the analysis of technical smart home characteristics, focused on inherent technologies, rather than the prioritisation of residential consumers for whom these technologies are ultimately designed. Therefore, these explorations proposed HEMS design trajectories for future smart homes. Yet, this overemphasis on the current technical advancements triggered a dissonance. Moreover, Kim et al. (2021) underlined the importance of reflection on residential consumer behaviour concerning the HEMS and therefore advocated for a bottom-up approach, to realise smart grid objectives for stakeholders such as utilities, grid operators, and governments. This suggests a design initiation from the residential consumer-level, gradually advancing towards strategic goals within the higher levels. Therefore, this study oriented around residential consumers, the ultimate end-users for whom the HEMS is designed. Therefore, the central research question of this study stated:

"How to design a value proposition for a Home Energy Management System aimed to enhance residential consumer adoption?"

2. Theoretical Framework

Within this chapter, a lens through which the main elements of the central research question from this paper were analysed is provided. Therefore, marking the scope of the study. First, the central research question was dissected, after which all its elements were clarified comprehensively and coherently. Then, all elements were linked to relevant theories, frameworks and models. After having extensively elaborated on all the elements of the paper's central research question and constructing the Theoretical Framework accordingly, a concise enumeration of the key takeaways is provided for this summary below.

2.1 HEMS definition

Within the first subchapter, several HEMS definitions that were extracted from related literature are provided, serving as the foundation for the paper's formulated HEMS definition, which was thereafter set and stated the HEMS as: a sophisticated IoT-based system, capable of minimizing electricity expenses for residential consumers, by generating optimal consumption schedules through an integrated DR tool that considers a multitude of factors. Furthermore, crucial smart home components under the purview of the HEMS encompass, but are not limited to, private (PV) solar panels, home batteries, heat pumps, EVs, and EV-associated charging station.

2.2 HEMS benefits for residential consumers

Based on eleven distinct HEMS benefits for residential consumers, identified within literature, four core HEMS benefits were ultimately integrated within the Theoretical Framework's second subchapter. Moreover, several of these incorporated (multiple) sub-benefits. Given that these benefits are factors that are theoretically capable of enhancing residential consumer adoption, it was essential to discover which of these benefits would practically be identified and/ or recognized by residential consumers, thereby confirmed as beneficial and which specific benefits were not perceived as such within the study. Moreover, it was deemed crucial to ascertain the underlying factors responsible for causing the above.

2.3 Enhancing residential consumer adoption

Related to this, the *Innovation-Decision Process (IDP)* model and the *Technology Acceptance Model (TAM)* were introduced and integrated as theoretical foundation for enhancing residential consumer adoption within the Theoretical Framework of the paper. In particular, the *relative advantage* of the IDP's *persuasion characteristics* and the *Perceived Usefulness*, as well as *Perceived Ease of Use* dimensions of the TAM could be leveraged within the study to emphasize the core HEMS benefits for residential consumers within the value proposition, since its ultimate design aim was to enhance residential consumer adoption of the HEMS. Therefore, the IDP and TAM were expected to portray a crucial role within the research, related to enhancing the residential consumer adoption potential within the value proposition, as well as increasing residential consumer understanding related to the four determined core HEMS benefits.

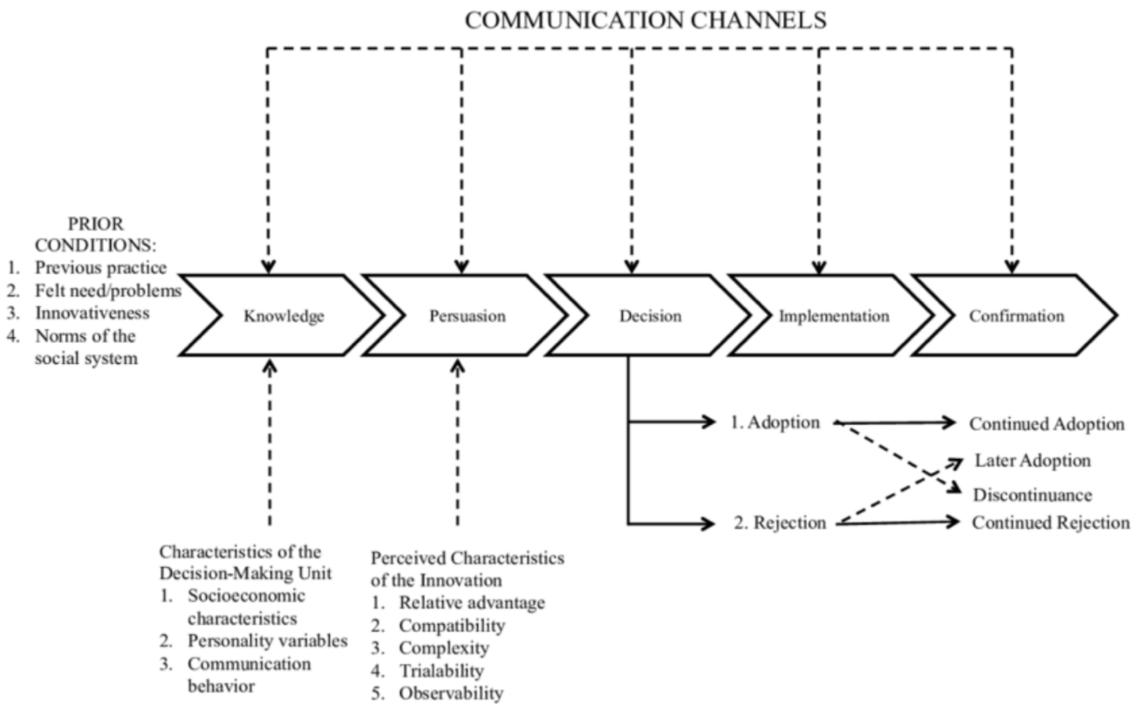

Figure 1. The Innovation-Decision Process (Rogers, 2003)

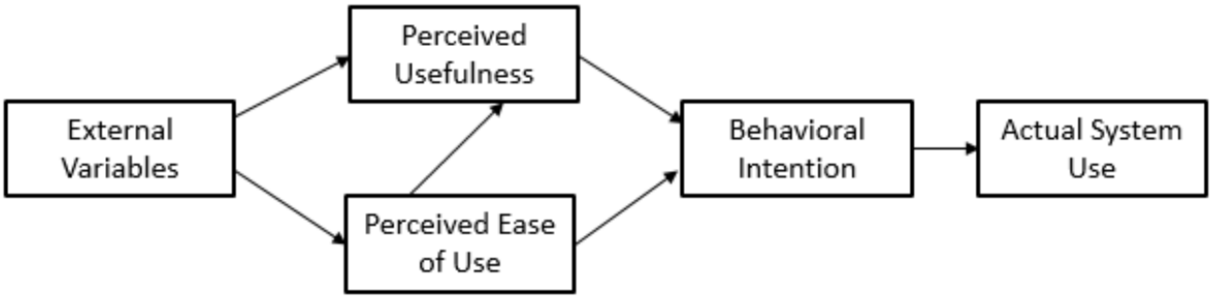

Figure 2. The Technology Acceptance Model (Venkatesh & Davis, 1996)

2.4 Designing a value proposition for the HEMS

Lastly, the *Value Proposition Canvas (VPC)* was integrated within the Theoretical Framework of the study as well since this concept was ultimately utilised as the supporting tool to actually design the value proposition for the HEMS of the research.

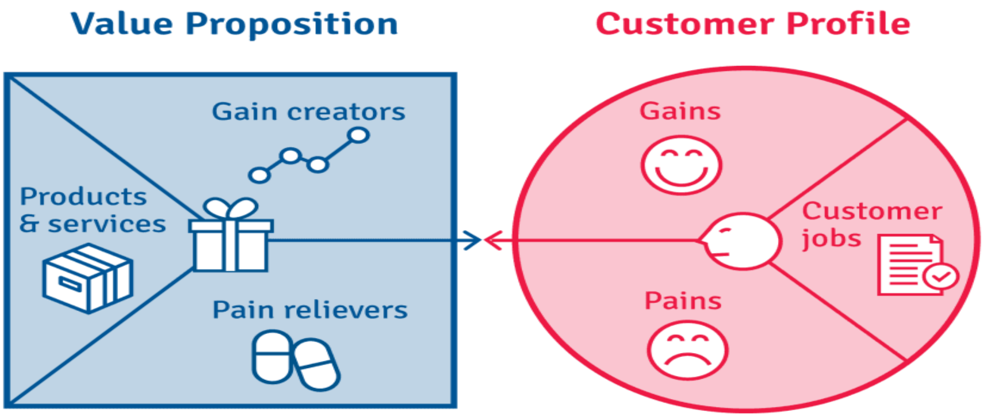

Figure 3. The Value Proposition Canvas (Osterwalder et al., 2014)

3. Methodology

The third chapter delved deeply into the processes that were conducted within the study to achieve *Fit* between the *Value (Proposition) Map* side of the VPC and the *Consumer Profile* side. Furthermore, the chapter in detail describes and explains the design science research approach that was followed during the study, in an attempt to answer the central research question of the paper. Moreover, shedding light on the reasoning that underpinned the conducted decisions during this process. Therefore, the chapter serves as a roadmap through all the iterative design stages of the study, from the initial problem identification and research motivation to the final re-design of the Value Proposition Canvas for the HEMS, as proposed treatment for the problem context of this study. Alongside this, the methods that were employed to validate and evaluate this treatment's effectiveness are explained within the chapter, by detailing the specific techniques and measures that were chosen, as well as their application and significance within the context of the design study. Furthermore, the data collection and analysis methods that were utilised are explained, offering an overview of the data's relevance, the process through which it was gathered, and the exact analysis conducted to extract meaningful findings and insights.

3.1 The utility collaboration

As mentioned above, the study was conducted in collaboration with an existing utility. This collaboration strengthened the motivation and aim of the study, as it allowed the opportunity to integrate two crucial stakeholder perspectives related to the residential consumer energy sector within the design process of the HEMS value proposition. Additionally, this collaboration enabled and fostered the gathering of first-hand data from both a utility as well as residential consumers. This, in turn, contributed to the alignment within the Value Proposition Canvas that was utilised within the study, thereby fostering Fit.

3.2 Theoretical design science foundation for the study's research methodology

According to Vom Brocke et al. (2020), design science research builds upon prior design knowledge, to create innovative designs and novel understandings. Subsequently, future design problems are able to benefit from this knowledge. Therefore, the research methodology of the study was built upon three existing as well as established contributions within the design science research literature, namely: Hevner et al. (2004), Peffers et al. (2007) and Wieringa (2014). Below, detailed reasoning for integrating each of these contributions is described:

I. **Hevner et al. (2004):** While constructing the design science research methodology for the research, the seven guidelines for design science in information systems research, proposed by Hevner et al. (2004) were found as the most established contribution within design science literature. Therefore, this design science contribution was integrated as the starting point that could provide framework and scope limits for the design process of the value proposition for the HEMS.

II. **Peffers et al. (2007):** Thereafter, the DSRM of Peffers et al. (2007) was identified as the most established research methodology within design science literature. Although the DSRM is not necessarily described as a linear process, this contribution was integrated to provide guiding directions within the broad design scope that was determined. Therefore, the DSRM was utilised to form an established approach foundation for the design process of the value proposition from scratch.

III. **Wieringa (2014):** Thirdly, the book of Wieringa (2014) was integrated within the study to strengthen, extend and modernise the DSRM from Peffers et al. (2007), as this book was observed to emphasize greater on the validation process within design science. Moreover, the *treatment* terminology of Wieringa (2014) was deemed more suitable instead of *solution* (Hevner et al., 2004 & Peffers et al., 2007), considering the problem context of lacking residential consumer HEMS adoption. Ultimately, the four design stages composed of eleven conducted steps, were constructed from joint inspiration that was primarily gained from the design cycles of Wieringa (2014) and the DSRM of Peffers et al. (2007). Furthermore, incorporating the principles of Hevner et al. (2004) as secondary theoretical backbone layer and for determining scope limits related to the design process of the value proposition.

3.3 The study's design science research methodology

Ultimately, the conducted design science research methodology of the study consisted of four design stages, that were composed out of eleven conducted steps.

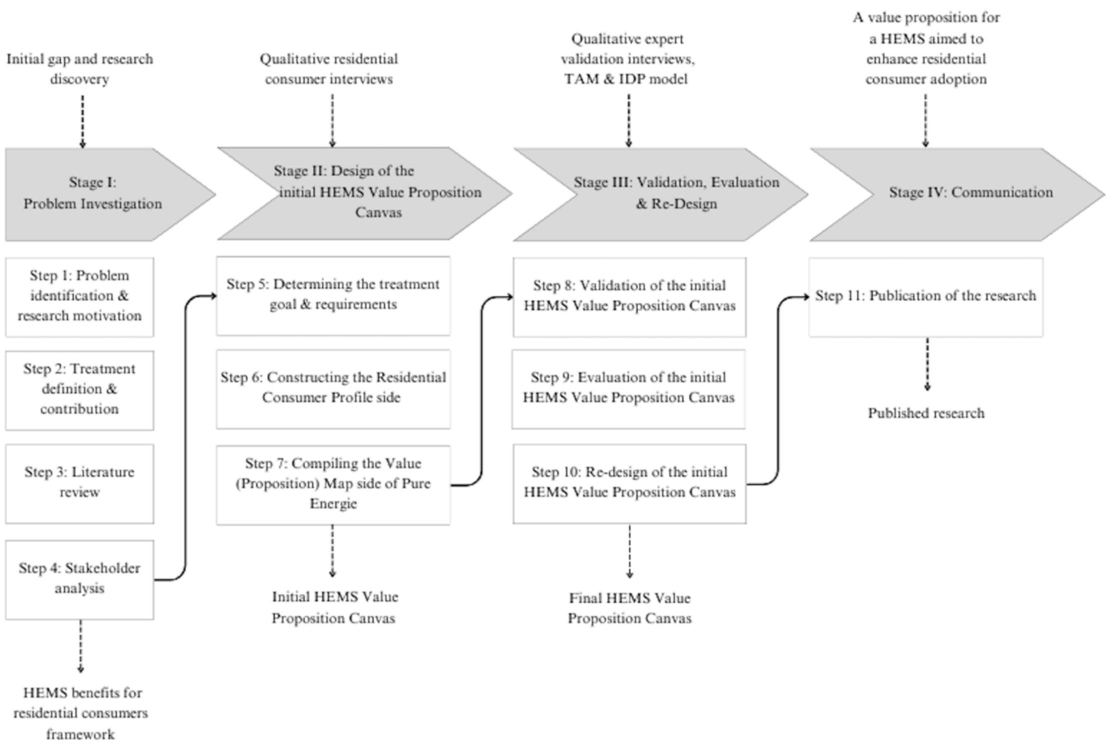

Figure 4. The design science research methodology of the study

4. The Design Process of the Initial HEMS Value Proposition Canvas

At this stage of the research, a comprehensive understanding of the problem and its context were precisely established. Furthermore, an extensive explanation was formulated concerning the anticipation that the formulation of an adoption-enhancing value proposition for a HEMS could serve as potential treatment for the lacking residential consumer adoption of the system. Also, each element derived from the central research question was examined individually. Specifically, focusing on the HEMS benefits for residential consumers and integrated models (i.e., IDP and TAM) with adoption-enhancing potential. Finally, the completion of the stakeholder analysis signified the completion of the initial stage of the research, namely the "Problem Investigation" stage as well. This progression meant that the second stage, labelled as the "Treatment Design" stage could now be initiated.

Therefore, this chapter within the research paper aims to detail all the procedures that were executed within the creation of the actual Value Proposition Canvas, commencing with the determination of a clear treatment goal, as well as the establishment of several specific treatment requirements. The conclusion that emerged from the stakeholder analysis was that the underlying stakeholder objectives and motives for residential consumer adoption of the HEMS remained inadequately charted. Therefore, this chapter provided an elaborate explanation regarding the manner in which the Residential Consumer Profile was constructed. As described within the Methodology chapter, data was accumulated from residential consumers through qualitative focus group interviews. This data proved instrumental in unveiling valuable insights relating to the adoption attitudes of these consumers towards the HEMS. Utilising these findings, the Residential Consumer Profile was ultimately constructed. Upon completion of this task, the Value (Proposition) Map of the utility was compiled. This process incorporated all the data acquired from internal (HEMS) meetings, conferences, minutes, strategic documentation, as well as numerous explicit dialogues. Specifically, data clarifying the manner in which the utility intended to provide value to their residential customers.

5. Validation & Evaluation

Within this chapter, the initial HEMS Value Proposition Canvas that was outlined within the previous chapter of the paper is validated through four qualitative expert interviews. Furthermore, it is evaluated whether the HEMS Value Proposition Canvas met the treatment goal and requirements that were determined. Lastly, the key findings of the study are discussed in relation to the application of the Innovation Process-Decision model and the Technology Acceptance Model, on the basis of which the final design for the HEMS value proposition aimed to enhance residential consumer adoption was designed within the final chapter of the research paper.

6. Presentation of the Final HEMS Value Proposition Canvas

This last chapter of the research paper presents the final design of the HEMS Value Proposition Canvas. After that, the canvas is reflected on, resulting in the description of conclusions that were drawn. Finally, three of the study's limitations are addressed as well as three directions for future research are provided. However, as stated earlier, the utility in question strongly desires these findings as well as the majority of content from all the chapters above to remain confidential until 2025. Again, merely the structures of these chapters were therefore described within this public summary. Nevertheless, as mentioned in the beginning, the researcher of the paper, the University of Twente and the utility in question agreed that the complete research paper will be made publicly available on the 1st of January 2025.

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