Bridging the Cost Gap: A Comprehensive Analysis of CAPEX and OPEX for Smart Home Transition from a Provider's Perspective

Nilton F. S. Seixas, Adriano H. O. Maia[a], George P. Pinto[b], Dhyego Tavares M. da Cruz[c], Bruno P. Santos[d], Ivan do C. Machado[e], Eduardo S. Almeida[f], Frederico A. Durao[g], Maycon L. M. Peixoto[h], Gustavo B. Figueiredo[i] and Cassio V. S. Prazeres[j]

Institute of Computing, Computer Science Department, Federal University of Bahia (UFBA), Salvador, Bahia, Brazil
{*nilton.seixas, adriano.maia, george.pacheco, dhyegocruz, bruno.ps, ivan.machado, eduardo.almeida, fdurao, maycon.leone, gustavobf, prazeres*}*@ufba.br*

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Abstract: The urgency of addressing global warming has driven global efforts to enhance energy efficiency and transform energy acquisition methods. In this context, the adoption of smart technologies has gained relevance across various domains, including smart cities and smart homes. While smart cities are often promoted through government initiatives, transforming conventional homes into smart homes largely depends on consumer adoption. However, there is a significant gap in the literature regarding the implementation costs and benefits of this transition, with many studies focused on unrealistic scenarios tailored to the average American consumer profile. This study aims to fill that gap by proposing a methodology to estimate the conversion of conventional homes into smart homes, accounting for both capital expenditures (CAPEX) and operational expenditures (OPEX). The proposed approach seeks to enable an affordable transition for a wider range of consumer profiles. Four case studies are presented to demonstrate how smart systems can be integrated into homes, maximizing economic and environmental benefits for end-users. Additionally, the paper analyzes the commercial relationship between manufacturers and smart environment providers, exploring acquisition and operational cost models. As an alternative to the traditional device-based business model, the study suggests a subscription-based system, supported by the continuous delivery of smart solutions, promoting greater customer retention and scalability.

1 INTRODUCTION

The emergence of smart environments has ushered in an era where billions of devices are seamlessly connected to the Internet. The current count surpasses 16 billion devices (Sinha, 2023), exceeding twice the global population of approximately 8 billion. Integrating home and street devices with 5G networks has facilitated a profound transformation across various sectors, including the economy, health, agriculture, and education. This transformative landscape has given rise to the Internet of Things (IoT) field, providing a platform to comprehensively study and understand the intricate phenomena associated with this interconnected web of devices.

The IoT establishes a paradigm connecting dayling physical objects to the Internet, enabling seamless communication. Coined by Kevin Ashton (Ashton, 2009), the term 'Internet of Things' envisions a world where these interconnected 'things' can communicate, collect data, and make informed decisions. The IoT provides advantages like improved resource utilization, increased productivity, and an enhanced quality of life for human communities. Meanwhile, smart environments are characterized "*as one that can acquire and apply knowledge about the environment and its inhabitants to improve their experience in that environment*" (Cook and Das, 2007). In this sense, the IoT stands as a fundamental enabler

[a] https://orcid.org/0009-0007-1739-4295
[b] https://orcid.org/0000-0002-6082-9211
[c] https://orcid.org/0009-0005-1061-9733
[d] https://orcid.org/0000-0003-4501-2323
[e] https://orcid.org/0000-0001-9027-2293
[f] https://orcid.org/0000-0002-9312-6715
[g] https://orcid.org/0000-0002-7766-6666
[h] https://orcid.org/0000-0002-4851-5228
[i] https://orcid.org/0000-0001-9756-378X
[j] https://orcid.org/0000-0003-0197-0909

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of smart environments, including smart homes, smart cities, and smart health, among others (Gomez et al., 2019).

The IoT-enabled Smart Homes pose as an important application of IoT. Their technologies have revolutionized the way we interact with our living spaces, offering a multitude of possibilities for utilizing IoT devices (Martins et al., 2024; Jr et al., 2024). Their innovations are pivotal in enhancing our daily lives by monitoring and adjusting various aspects of our homes. From measuring environmental conditions to seamlessly overseeing household appliances and even regulating access to our homes, Smart Homes provide security, energy efficiency, low operating costs, and convenience (Campos et al., 2024). Moreover, they possess a dynamic and flexible nature, allowing them to accommodate the evolving requirements of the home residents. Additionally, they have an adaptable infrastructure capable of integrating with devices from different providers and standards (Domb, 2019).

Although smart homes seem to be the future for homes and despite the advantages highlighted earlier, embracing smart home systems requires an investment in both hardware and setup (Larionova et al., 2024). Additionally, we also face a significant impediment to their widespread adoption that lies in consumers' perception that the investment in this transition may not justify the associated costs. This perception forms a barrier, hindering the broader acceptance of smart home solutions (de Souza Dutra et al., 2020). Moreover, while there has been extensive scrutiny of capital and operational expenditures (CAPEX and OPEX) in the context of smart cities, particularly in energy-related domains like smart lighting and grids, research on the corresponding costs for smart homes remains scant. Previous studies (de Souza Dutra et al., 2020; Larionova et al., 2024) have provided preliminary CAPEX/OPEX estimations for smart homes, with estimated costs distant from the average American. Hence, there is a critical need for a more comprehensive assessment to facilitate a smooth transition from traditional residences to smart ones. Additionally, it's essential to delve deeper into the operational expenses associated with managing data generated by smart home devices.

To address the aforementioned problem, this paper introduces a novel methodology aimed at estimating a cost-effective CAPEX for end-users looking to upgrade their residences into smart homes, alongside OPEX considerations for smart home providers. These providers manage the influx of messages and API calls from smart devices, facilitating the delivery of smart services to end-users. This approach streamlines the transition from conventional houses to smart ones by eliminating the need for users to invest in expensive devices outright. The contributions of this paper include: (i) methodology for estimating CAPEX for smart end users and providers; (ii) methodology for estimating OPEX for smart providers; (iii) introduction of a new player: smart providers; (iv) four smart home case studies; (v) suggestion of subscription plans for monthly billing.

The remainder of this paper is organized as follows: Section 2 presents the related works. Section 3 describes our methodology. Section 4 summarizes and discusses the results of our study cases. Finally, Section 5 summarizes our contributions and presents some future works.

2 RELATED WORKS

The energy consumption has become a matter of greater importance to the world, especially after the pandemic. The authors in (Parežanin, 2023) underscores the critical necessity for the European Union to diminish its energy reliance on the Russian Federation. Central to this imperative is the exploration of adopting smart grids across the twelve member states of the bloc, a move fraught with multifaceted challenges. The authors interrogate key aspects, such as the readiness of distributed system operators to seamlessly integrate services with smart meters, as well as the feasibility of categorizing member states based on energy usage levels, among others.

Furthermore, the authors conduct a thorough analysis of the costs and advantages linked to deploying smart meters across all member states, presented in a detailed tabular format. Despite the growing significance of Smart Homes as a solution for energy conservation and reducing energetic dependency, their absence in the discussion warrants further investigation. Subsequent subsections will explore the CAPEX/OPEX associated with implementing smart homes and other intelligent environments in greater detail.

2.1 Smart Homes

The paper (de Souza Dutra et al., 2020) presents a comprehensive framework for determining a set of combinations of home appliances, taking into account factors such as the structural layout of the house, local weather conditions, pricing, and energy consumption. The selected home appliances considered in this study include wind turbines, photovoltaic panels, energy storage systems, electric vehicles, heating, air conditioning, and ventilation. Additionally, the authors have provided a detailed cost analysis of these appliances, ranging from USD 424.31 to USD 31,775.14.

While the paper introduces an intriguing methodology for generating appliance combinations based on pricing considerations, it is pertinent to note that prior research, particularly in the related works section, has utilized mixed-integer linear programming (MILP) techniques to yield superior results. To enhance the credibility of the proposed framework, it is recommended to compare its outcomes directly with those obtained through MILP, thereby gauging its proximity to optimal solutions.

Furthermore, the selection of appliances for experimentation may not adequately address the transition from conventional to smart homes. The absence of discussion regarding existing appliances within households also raises questions about the practicality and effectiveness of the smart home implementation. A more thorough examination of household appliances is imperative to facilitate a seamless transition towards smart homes, ensuring compatibility and integration with pre-existing systems.

The paper (Larionova et al., 2024) introduces a compelling study aimed at elucidating the potential energy and operational cost savings achievable through the adoption of smart appliances, including smart thermostats, lighting systems, security systems, and HVAC units. Initially, the authors delineate the CAPEX involved, detailing the costs associated with each equipment, ranging from USD 250.00 to USD 1800.00, with installation and setup expenses totaling USD 500.00, amounting to USD 3720.00. Subsequently, they present the OPEX through a tabular representation showcasing monthly energy savings from each device under scrutiny, cumulatively reaching USD 240.00.

While the paper serves as a commendable foundation for assessing the costs of integrating smart appliances into conventional households, it falls short of adequately addressing the concept of a smooth transition. Specifically, there is a notable oversight in considering the average income levels of individuals, particularly in the context of the USA, along with associated living expenses. For instance, the average salary is noted as USD 4,537.48, while the cost of living for a single person, excluding rent, is USD 1,170.40. Factoring in average rent in suburban areas, the total living expenses surge to USD 2,943.48, leaving a remainder of USD 1,594.00 for discretionary spending. This crucial aspect merits further attention to ensure a more comprehensive evaluation of the feasibility and practicality of transitioning to smart homes ((Zillow), 2024).

2.2 Other Smart Environments

The paper (Cacciatore et al., 2017) investigates the cost analysis of implementing smart lighting in smart cities, evaluating four solutions: Current implementation (CUR), Delay-based (DEL), Encounter-based (ENC), and Dimming (DIM). These solutions involve combinations of two types of lighting devices: Light-Emitting Diode lamps (LEDs) and High-Pressure Sodium (HPS) lamps. LEDs offer the capability to adjust light intensity, whereas HPS lamps only provide on/off functionality.

In the CUR solution, traditional lamps are utilized, operating at full intensity for a predetermined duration. The DEL solution utilizes both LED and HPS lamps, activating at full intensity when sensors detect people within a designated radius R and turning off when no presence is detected within a period W. The ENC proposal activates lights in the morning upon detecting the presence and remains on for a period W, exclusively employing HPS lamps. Lastly, the DIM solution adjusts light intensity based on the number of people detected within a radius R, utilizing only LED lamps. The authors ascertain that the DIM solution, leveraging LEDs, yields the most favorable energy savings.

The study in (Yaacoub and Alouini, 2020) advocates for embracing the concept of ”smart living” as a means to counter the migration from rural to urban settings. They define smart living as the integration of advanced technologies and connectivity to stem or mitigate the flow of individuals to urban centers. Achieving this objective entails ensuring robust connectivity in rural areas to facilitate remote work opportunities, leveraging solar panels for sustainable energy generation, implementing high-speed rail systems for occasional urban transit, and employing virtual and augmented reality tools to enhance educational experiences for children. To support the realization of these initiatives, the paper outlines the necessary capital and operational expenditures for essential infrastructure components such as microwave towers and equipment, spectrum licenses, fiber optic networks, satellite systems, and related installations.

The paper (Mehta and Eleftheriadis, 2022) introduces a framework aimed at assessing the expenses associated with deploying edge cloud resources, with the goal of mitigating energy consumption's effects on the nodes within the electrical grid. This framework categorizes CAPEX into two distinct categories: active and passive equipment. Active expenditures encompass the primary costs associated with servers, radio equipment, and network infrastructure. Conversely, passive expenditures encompass expenses related to building construction, procurement, and installation of power distribution systems, as well as cooling infrastructure. Additionally, OPEX is bifurcated into two segments: the electricity required to power and cool the servers and operational costs covering aspects such as security measures and maintenance activities.

3 METHODOLOGY

In this section, we delineate a comprehensive methodology to estimate the expenses of transforming a traditional household into a Smart Environment. To achieve this, we explore two key cost dimensions. Firstly, we examine the perspective of the company offering Smart Environment solutions (OPEX). This entails outlining all expenditures associated with licensing communication channels between device manufacturers and the new provider, the procurement costs of sensors for resale, licensing fees for Software Development Kits (SDKs) required for implementing intervention applications on the devices, and cloud hosting expenses for delivering associated services. We also highlight the communication costs of the device with the manufacturer's cloud, charged monthly throughout the entire useful life of the device. Secondly, we delve into the costs from the customer's viewpoint, encompassing the acquisition of Smart Environment solutions and projecting potential expenses (CAPEX).

3.1 OPEX

In this subsection, we describe our approach to analyzing and calculating the costs related to operating the devices through a Smart Environment provider. We aimed to understand all the values involved in the relationship between Smart Devices manufacturers and the new Smart Devices provider. This work aims to establish a guide that provides an overview of costs for a new provider so that new entrants can adequately consider the values related to CAPEX and OPEX of their new venture, having detailed information to avoid unforeseen circumstances and maintain financial health in their new operation. Furthermore, the customer-centric aspect may offer valuable commercial insights for composing sensor and device sales kits or establishing a monthly service plan for recurring income. Additionally, it allows the customer to assess their investment in this type of solution tangibly. To carry out this study, we followed **five steps**, which are described as follows.

Step 1

We researched potential Smart device manufacturers and their methods of establishing partnerships with new providers interested in commercializing and distributing these devices.

Step 2

We selected a manufacturer to conduct the case study and investigated the commercial and contractual conditions for establishing partnerships between the manufacturer and the new provider.

Step 3

After analyzing these conditions, we identified the related costs within two main areas. The first area pertains to acquiring a physical batch of specific devices, such as power plugs, smart bulbs, robotic vacuums, and electronic locks, among others. The values are presented in product batches and are based on US dollars. The second area involves licensing for communication between the devices and the manufacturer's cloud. In this scenario, the messages are charged to the provider from the moment of sale until the device is discarded by the customer.

After selecting the manufacturer and obtaining the devices, It is essential to highlight the associated costs for the interactions among the device, manufacturer, and cloud provider, considering the associated costs. The devices typically communicate using the Message Queuing Telemetry Transport (MQTT) protocol, renowned for its efficient transmission of data over networks with limited resources. MQTT is favored in IoT environments due to its simplicity in implementation and its ability to minimize data usage and energy consumption during operation.

The *MQTT protocol* is used in this context to periodically report their status whenever there is any change in the environment or configuration, referred to by the manufacturer as a message subscription. Another form of communication is a direct intervention by a user or application in the device, whether to turn it on, or off, change its configuration, or request its current status, this scenario is referred to by the manufacturer as an API call.

Figure 1 provides a general overview of how the communication scheme between the device and the manufacturer's cloud operates. Additionally, the same figure illustrates how the new provider physically operates in this context.

In general, there exist charges regarding communication licensing between companies. In this analysis, the manufacturer offers three annual plans with

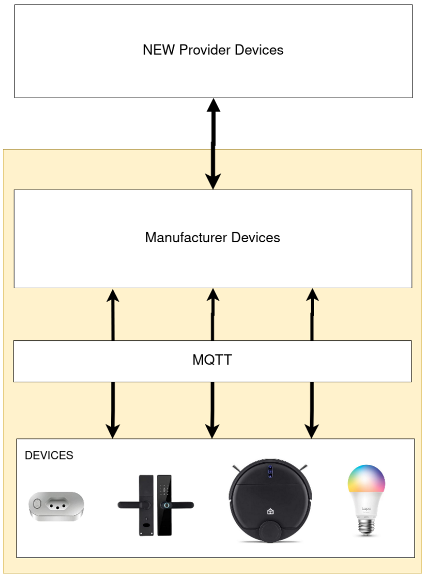

Figure 1: Device communication scheme.

fixed values charged in US dollars. These plans feature fixed values for specific monthly quotas. In other words, regardless of the chosen plan, the tariffed amount will remain predetermined if the quota limit is not reached. However, if the quota limit is exceeded, an excess fee will be charged and added to that month's quota. This excess fee is calculated per million subscription messages and API calls and is charged in US dollars. Additionally, it's worth noting that the excess fees differ between subscription messages and API calls. The manufacturer also applies different rates between China and the rest of the world, with lower rates in the former. This structure is independent of the chosen plan, with only a potential difference in value based on the selected plan.

In the monthly plans, the manufacturer under analysis initially offers a trial plan, which is solely for experimentation purposes. In this case, the quota is set at a small value, and when the limit is exceeded, there is a charge for the automatic transition to the subsequent plan. Additionally, the manufacturer restricts the number and types of devices for this plan. The intermediate plan is viewed by the manufacturer as the bestseller and is geared towards sales consolidation and structural expansion of the new provider. The monthly quota for both subscription messages and API calls is set at over 250 million each, aiming to be sufficient for an entry-level provider to operate with minimal excess during their first year. The third and final plan is seen by the manufacturer as corporate and features a quota approximately double that of the intermediate plan. This plan targets an established smart home provider with a definitive product mix.

To determine the method for calculating the cost per device, we first measured the message subscriptions performed by a plug-in operation in the lab for one hour. Then, we performed the multiplications to arrive at the monthly consumption of message subscriptions, and to determine the value of the API calls; we assumed that it was equal to the number of message subscriptions collected.

Finally, we divided the result of these two items by one million and multiplied it by the specific overage rate. The result is then added together, generating the cost of the device in relation to the communication license per month. It is worth mentioning that we used the overage values to establish a calculation mechanism; however, it is important to remember that within the plans offered, there are monthly quotas.

This cost serves the provider as part of the composition of the sales price, in addition to a point of attention in the development of the sales planning and the maintenance of the entire operation, as this cost must be sustained by the provider throughout the entire useful life of the device. In light of this, the planning should consider not only the initial sales costs but also the ongoing expenses related to communication and maintenance, ensuring that the operation remains financially viable and sustainable. Equation 1 illustrates this calculation mechanism.

$$C = \left(\frac{SMH \times 24 \times 30}{1{,}000{,}000} \times CSM\right) + \left(\frac{APIH \times 24 \times 30}{1{,}000{,}000} \times CAPI\right) \quad (1)$$

where C is the cost per device per month in US dollars, SMH stands for the number of message subscriptions per hour, CSM indicates the excess cost per message subscription per million, $APIH$ refers to the quantity of API calls per hour, and $CAPI$ is the value of excess cost per API call per million.

Step 4

A requirement from the device manufacturer for the new provider to interact via its application on its smart devices is the acquisition of the SDK. This resource is essential for the provider to effectively abstract the manufacturer from the customer's perspective, with the customer using the application assuming that the particular device is manufactured and provided by the provider. The cost of the SDK is annual and based on US dollars.

Figure 2 provides a general overview of how the communication scheme between the device and the manufacturer's cloud operates. It considers the adoption of the SDK and cloud hosting service. To determine the method of calculating the annual cost of a provider, add up the yearly communication licensing plan, the annual SDK cost, and the annual cloud hosting cost for the new provider. The Equation 2 illustrates this calculation mechanism.

$$\text{AnnualCost} = \text{AnnuaPlan} + \text{SDK} + (\text{Cloud} \times 12) \quad (2)$$

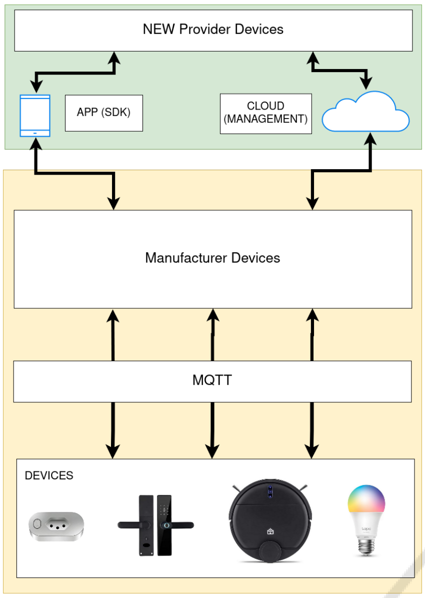

Figure 2: Device communication scheme with the adoption of the SDK and cloud hosting service.

Step 5

For the new provider to have an overview of all devices within its domain, apply additional services, or simply manage them in a global view, the acquisition of cloud servers to support these services is necessary. Therefore, in this work, we estimated a minimum structure for adopting a platform to manage all devices of a new provider and sought prices from providers such as AWS and Azure to estimate the costs of this operation.

Important to highlight that this value may be subject to additional charges due to any monthly excesses. In this case, simply apply the mechanism of Equation 1 for the months and add it to the annual cost (Equation 2).

$$\text{Annual\_Cost\_Exc} = \text{Annual\_Cost} + (C \times \text{Dev\_Exc} \times \text{Months\_Exc}) \quad (3)$$

Where the AnnualCostExc is the final value of the year in case there are excesses, AnnualCost is the total cost of the year without excesses, C is the cost per device per month in US dollars, DevExc is the number of devices that had excesses, and MonthsExc is the number of months that had excesses in the year. In this work, we are abstracting costs related to labor, compliance with legislation, and accounting, among others. Thus, we highlight the more specific costs of the commercial relationship between the manufacturer and the new smart environment provider.

Table 1: Symbol table for CAPEX, OPEX, and equations.

Symbol	Description
CAPEX	Total capital expenditure for smart devices
n	Number of devices
Device_i	The i-th smart device
UnitCost_i	The cost of the i-th smart device
C	Operational expenditure for communication licensing per device
SMH	Number of message subscriptions per hour
CSM	Excess cost per message subscription per million
$APIH$	Number of API calls per hour
$CAPI$	Excess cost per API call per million
24	Hours per day
30	Days per month
1,000,000	Normalization factor (per million)
Annual_Cost	Total annual cost without exceeding quota
Annual_Plan	The annual cost of the communication licensing plan
SDK	The annual cost of the Software Development Kit (SDK)
Cloud	The monthly cost of cloud hosting services
Annual_Cost_Exc	Total annual cost with excess quota charges
C	Cost per device per month (for excess calculations)
Dev_Exc	Number of devices that exceeded the monthly quota
Months_Exc	Number of months where the quota was exceeded

3.2 CAPEX

We applied a customer-centric approach in our cost analysis to assess the feasibility of Smart Environment and Smart Homes solutions. This study was conducted to evaluate the cost-benefit for various types of customers, considering factors such as the size of the residence, number of rooms, family size, and purchasing power, among others. This analysis aims to understand the financial investment required by users for the transition from a conventional house to a smart home, as well as to provide commercial guidance for new providers in this market segment.

To carry out this task, we initially needed to define usage models based on certain criteria. For this purpose, we used data from ((Zillow), 2024) to understand the financial potential and associated cost of living issues for American citizens. Subsequently, we had to consider which devices would have the greatest utility in the context of a smart home, taking into account the legacy structure of a conventional house.

The definition of this device acquisition structure is important for sizing the capacity that a provider must have to support an operation that reflects this acquisition. For example, the CAPEX of all devices acquired by all customers is calculated by summing the total number of devices multiplied by the unit cost within a purchase lot offered by the manufacturer. This equation 4 illustrates the relationship between the initial investment represented by the acquisition of the device lots and the consequent number of active devices at customers. Providers need to consider CAPEX comprehensively, as these devices will be sending messages and generating monthly costs while they are active, potentially consuming all associated profitability.

$$\text{CAPEX} = \sum_{i=1}^{n} (\text{Device}_i \times \text{UnitCost}_i) \quad (4)$$

Following this approach, we determined that smart plugs, light switches, and universal remotes would have the highest effectiveness in terms of conversion to a smart environment. These devices facilitate the transformation of conventional appliances into smart ones; for example, a smart plug can automate the occasional shutdown of a freezer that might otherwise remain on for the entire month.

Table 2: Basic smart devices costs.

Devices Required (USD)	
Smart plug	17.80
Light Switch	19.80
Universal Control	17.00
Mesh router	69.00

Another key point highlighted in this analysis is the high dependence on device connectivity, considering the constant need for message exchange with the cloud. To address this, we researched and recommended mesh routers to meet the specific needs of a smart home environment. Table 2 summarizes the costs of basic devices to convert conventional houses into smart ones.

4 STUDY CASES

In this section, we will present the cost analysis we conducted for acquiring Smart Environment solutions to convert a conventional house into a smart home (CAPEX). Based on the analysis presented in Section 3, Subsection 3.2, we defined four usage models, taking into account the utilization of the smart environment and the quantitative aspects related to house size and the financial potential of American citizens.

This analysis is essential for guiding and aligning a provider's operational costs, considering the mix of different types of residences that will be explored throughout this article. Understanding the variations in consumption profiles and the specific demands of each kind of residence enables the provider to adjust its strategies more precisely in terms of infrastructure and the services offered. This ensures not only a more efficient operation but also the opportunity to optimize resource allocation and improve profitability.

Considering this scenario, we will present the cost perspective for the end customer and estimate the number of residences for the development of the cost model for a service provider in the following subsections.

4.1 End Customer View

These models will be detailed below:

Smart Environment Starter Kit: The suggested Smart Environment starter kit is specifically designed to meet the needs of individuals living alone or couples who are at the early stages of their financial journey, with a growing yet still limited purchasing power. This proposal aims to provide an affordable and effective home automation experience for small to medium-sized residences, with up to 5 rooms. Table 3 provides a detailed breakdown of this composition.

Table 3: Cost analysis of the starter model.

Smart Environment Starter Kit				
Device	**Appliance**	**Quantity**	**Unit Price**	**Total Price**
Plug	TV	1	$17.80	$17.80
	Refrigerator	1	$17.80	$17.80
	Microwave	1	$17.80	$17.80
	Washing Machine	1	$17.80	$17.80
	Computer	1	$17.80	$17.80
	Outlets	1	$17.80	$17.80
	Fan	2	$17.80	$35,60
Light Switch	Light Switch	1	$19.80	$19.80
Universal Control	Air Conditioner - TV - TV Receiver	1	$17.00	$17.00
Router Mesh		1	$69.98	$69.98
			Total Equipment	**$249,18**

To ensure a smooth transition to a smart environment, the kit includes a variety of essential devices. Among them are 8 smart plugs, ideal for remotely controlling and monitoring the operation of various household appliances efficiently. Additionally, a smart switch is included to offer convenient lighting control throughout the home. For seamless integration of devices and a unified experience, the kit also features a universal remote, allowing control of multiple infrared-compatible devices, such as TVs and audio systems, through a single device. Lastly, a mesh router is recommended to ensure reliable and consistent Wi-Fi coverage throughout the residence, providing a stable connection for all smart devices. This combination of devices is designed to deliver comfort, convenience, and energy efficiency, all within an affordable budget for those taking their first steps into home automation.

Smart Environment Model 1: The suggestion for Smart Environment Model 1 is specifically aimed at families with at least 5 members, characterized by a stabilized yet constantly expanding purchasing power. The recommended residence for this scenario has a maximum of 8 rooms and aims to automate at least 17 different household appliances, ensuring a smart and efficient environment. The table 4 provides a detailed breakdown of this composition.

In this context, we recommend including 21 smart

Table 4: Cost analysis of the model 1.

Smart Environment Model 1				
Device	**Appliance**	**Quantity**	**Unit Price**	**Total Price**
Plug	TV	1	$17.80	$17.80
	Refrigerator	1	$17.80	$17.80
	Microwave	1	$17.80	$17.80
	Coffee Maker	1	$17.80	$17.80
	Air Conditioner	1	$17.80	$17.80
	Washing Machine	1	$17.80	$17.80
	Computer	1	$17.80	$17.80
	Printer	1	$17.80	$17.80
	Dishwasher	1	$17.80	$17.80
	Plugs	5	$17.80	$89.00
	Fan	1	$17.80	$17.80
	Air fryer	1	$17.80	$17.80
	Water filter	1	$17.80	$17.80
	Stove	1	$17.80	$17.80
	Freezer	1	$17.80	$17.80
	TV receiver	1	$17.80	$17.80
	Videogame	1	$17.80	$17.80
Switch	Light Switch	3	$19.80	$59.40
Universal Control	Air Conditioner - TV - TV Receiver	1	$17.00	$17.00
Mesh Router		2	$69.98	$139.96
			Total Equipment	**$638.36**

Table 5: Cost analysis of the model 2.

Smart Environment Model 2				
Device	**Appliance**	**Quantity**	**Unit Price**	**Total Price**
Plug	TV	3	$17.80	$53.40
	Refrigerator	1	$17.80	$17.80
	Microwave	1	$17.80	$17.80
	Coffee Maker	1	$17.80	$17.80
	Air Conditioner	2	$17.80	$35.60
	Washing Machine	1	$17.80	$17.80
	Computer	2	$17.80	$35.60
	Printer	1	$17.80	$17.80
	Dishwasher	1	$17.80	$17.80
	Plugs	16	$17.80	$284.80
	Fan	2	$17.80	$35.60
	Air fryer	1	$17.80	$17.80
	Water filter	1	$17.80	$17.80
	Stove	1	$17.80	$17.80
	Freezer	1	$17.80	$17.80
	TV receiver	3	$17.80	$53.40
	Videogame	1	$17.80	$17.80
Switch	Light Switch	8	$19.80	$158.40
Universal Control	Air Conditioner - TV - TV Receiver	3	$17.00	$51.00
Mesh Router		3	$69.98	$209.94
			Total Equipment	**$1095.74**

plugs, ideal for remote control and monitoring of a wide variety of household appliances, providing convenience and energy savings. Additionally, we suggest installing 3 smart switches to facilitate lighting management throughout the residence, ensuring comfort and safety for the entire family. For seamless integration and a unified experience, the kit also includes a universal remote, allowing convenient control of multiple infrared-compatible devices, such as TVs, audio systems, and other electronic devices, all from a single device. To ensure comprehensive and stable Wi-Fi coverage throughout the residence, we recommend including two mesh routers, providing reliable connectivity for all smart devices, regardless of their location in the house.

Smart Environment Model 2: The Smart Environment Model 2 suggestion is aimed at larger families, with at least 10 individuals, characterized by stable and defined purchasing power. The recommended residence for this scenario has a maximum of 12 rooms but with a considerable area compared to Smart Environment Model 1. Additionally, the aim is to automate at least 17 different household appliances, with redundancy in some cases, such as 3 televisions. The table 5 provides a detailed breakdown of this composition.

In this context, we recommend the inclusion of 39 smart plugs, providing remote control and monitoring of a wide variety of appliances, ensuring convenience and energy efficiency. Furthermore, we suggest installing 8 smart switches for lighting management and 3 universal remotes to facilitate control of entertainment devices throughout the residence. To ensure seamless integration and comprehensive Wi-Fi coverage, we recommend including 3 mesh routers. This will ensure a stable and reliable connection for all smart devices, regardless of their location in the house.

Smart Environment Model 3: The Smart Environment Model 3 suggestion is aimed at very large families or small businesses, such as those in the hospitality industry, with significant purchasing power. The suggested location has a maximum of 22 rooms, with a considerable area, and aims to automate at least 17 different household appliances, with redundancy in some cases, such as 5 televisions. The table 6 provides a detailed description of this composition.

Within this context, we highly advocate for the integration of 65 smart plugs, offering remote control and real-time monitoring capabilities for a diverse range of appliances. Moreover, we propose the installation of 25 smart switches dedicated to efficient lighting management, complemented by the addition of 5 universal remotes. These remotes serve to streamline device control across the entire residence or establishment, further enhancing the smart living experience.

Figure 3 shows a bar chart illustrating the capital expenditure (CAPEX) associated with each smart home model: the starter kit, model 1, model 2, model 3, and model 4. Each bar represents the total cost required to implement the respective model, highlighting the scalability and different investment levels of the smart home solutions offered from the end customer's perspective.

Table 6: Cost analysis of the model 3.

Smart Environment Model 3				
Device	**Appliance**	**Quantity**	**Unit Price**	**Total Price**
Plug	TV	5	$17.80	$89.00
	Refrigerator	2	$17.80	$35.60
	Microwave	1	$17.80	$17.80
	Coffee Maker	2	$17.80	$35.60
	Air Conditioner	5	$17.80	$89.00
	Washing Machine	1	$17.80	$17.80
	Computer	2	$17.80	$35.60
	Printer	1	$17.80	$17.80
	Dishwasher	1	$17.80	$17.80
	Plugs	30	$17.80	$534.00
	Fan	5	$17.80	$89.00
	Air fryer	1	$17.80	$17.80
	Water filter	1	$17.80	$17.80
	Stove	1	$17.80	$17.80
	Freezer	2	$17.80	$35.60
	TV receiver	3	$17.80	$53.40
	Videogame	2	$17.80	$35.60
Switch	Light Switch	25	$19.80	$495.00
Universal Control	Air Conditioner - TV - TV Receiver	5	$17.00	$85.00
Mesh Router		5	$69.98	$349.90
			Total Equipment	**$2086.90**

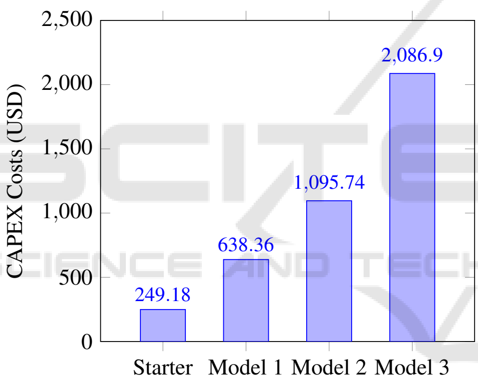

Figure 3: CAPEX for Different Smart Home Models.

To guarantee robust and consistent Wi-Fi coverage throughout the area, we strongly advise the incorporation of 5 mesh routers. This strategic addition ensures a stable connection for all smart devices, irrespective of their placement within the space. Carefully curated for optimal performance, this combination of devices promises unparalleled convenience, comfort, and efficiency in expansive family residences or commercial settings. It represents a noteworthy investment in the advancement of home or business automation, positioning stakeholders for a seamless transition into the future of smart living and operational excellence.

Also, Figure 3 effectively underscores the range of smart home solutions available, allowing consumers to select a model that aligns with their specific needs, household size, and financial capacity. The progressive increase in CAPEX from the Starter Kit to Model 4 demonstrates the flexibility of smart environment offerings, catering to a diverse spectrum of users, from individual homeowners to large families and small businesses.

4.2 Provider Cost Analysis

The definition of acquisition models for converting conventional homes into smart homes serves as a reference for a provider to design the costs associated with its operations, considering a specific volume of assets. This mechanism is essential for identifying the profitability of this type of operation. In addition to the costs related to acquiring a specific lot of devices, such as importation, logistics, storage, resale, marketing, post-sales, support operation, and infrastructure, the provider must calculate the monthly communication costs between the device and the manufacturer. This communication occurs automatically when the device reports its status or when the application requests information about its condition.

This scenario directly impacts the maintenance of the profit obtained from a direct sales transaction, which tends to be consumed over the equipment's lifecycle. To address this situation, the provider must ensure a high and constant volume of sales of this type of equipment or consider adding solutions to this structure. An effective strategy is to implement a subscription model, which enables recurring billing. In this way, the provider can accommodate these ongoing costs and establish a new source of revenue.

Table 7 presents an overview of the estimated monthly and recurring costs for a universe of 500,000 homes. We considered the costs associated with the development of the device management software, including expenses for the software development kit (SDK) necessary for creating the application. Additionally, the costs related to cloud servers, which are essential for managing the APIs and services that ensure the proper functioning of the platform, are included. We also accounted for the labor required to support this entire infrastructure, as well as the communication costs between the devices and the manufacturer. This comprehensive analysis is fundamental for understanding the financial viability of the project and for formulating strategies that ensure profitability over time.

With this analysis, we were able to project the recurring cost of each house model for the previously mentioned universe, using the mechanics of Equation 5.

$$\text{Cost\_P\_House} = \frac{\text{Mess\_Cost} * \text{Qtd\_Houses} + \text{Cost\_Cloud} + \text{Cost\_OPEX\_Empl}}{\text{Qtd\_Houses}} \quad (5)$$

Where Cost_P_House represents the monthly unit cost per house model, Mess_Cost refers to the total recurring cost of messages per house model for

Table 7: Cost Assessment - Provider Perspective per house.

Cost Assessment - Provider Perspective per house			
Description			
Monthly Operation Cost			
Capex Cost - AWS (Estimated)	$ 3,642.38		
Opex Cost - Employees (Estimated)	$ 172,384.64		
Number of Houses	500,000.00		
Model	**Message Cost**	**Operation Cost**	**Unit Cost per house**
House 1	$ 9.67	$ 5,014,895.75	$ 10.03
House 2	$ 19.35	$ 9,853,764.47	$ 19.70
Starter Kit	$ 19.36	$ 2,111,574.52	$ 4.22
House 3	$ 36.77	$ 18,563,728.16	$ 37.13

the month. Qtd_Houses pertains to the universe of 500,000 smart homes, while Cost_Cloud is the value associated with the cloud servers that support this large-scale operation. Finally, Cost_OPEX_Empl corresponds to the labor cost necessary to maintain this operation monthly. It is important to note that we are abstracting costs related to regulatory compliance, accounting, and other operational expenses. Thus, the focus is on the more specific costs of the commercial relationship between the manufacturer and the new smart environment provider.

This tool enables the understanding of the sales volume that the provider needs to maintain to support these recurring costs. By analyzing the costs of each model, we can identify the variations that directly influence the provider's financial sustainability. Furthermore, this projection aids in formulating recurring sales strategies, ensuring that the provider not only covers its expenses but also achieves additional recurring profitability.

Based on these results, the vendor can design business scenarios and assess whether current sales strategies, which rely exclusively on device transactions with customers, are sustainable in the long term. As illustrated in Table 7, there are fixed operational costs that occur monthly, regardless of whether the supplier carries out new sales transactions. In other words, even if sales are interrupted, the supplier's fleet of devices will continue to generate costs. This means that the profitability obtained from previous sales will have to be used to cover these ongoing operating costs.

In this scenario, during a sales plateau, where sales reach a point of stagnation, suppliers will face a direct impact on their financial health. The absence of new revenue streams to offset these costs may compromise the sustainability of the business in the medium and long term.

The graphs 4 illustrate these trends, highlighting the relationship between fixed costs, sales, profit, sending messages and time. Therefore, it is essential that providers diversify their monetization strategies and seek new sources of revenue to maintain the financial health of their operations.

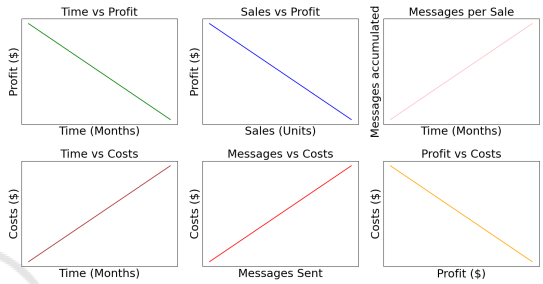

Figure 4: Trends in sensor transaction-based model.

When analyzing the relationships and trends presented in the graphs, it is observed that profit can be entirely consumed over time. Simultaneously, it is noted that as the volume of messages sent increases, whether through API calls or device status messages, monthly costs also rise. There is a direct relationship between sales and profit in this context: if sales stabilize at an equilibrium point, profit decreases as it gets absorbed by recurring costs.

These conclusions are supported by data analysis, which shows the increase in costs over the months, directly impacting profit. Over time, the accumulation of messages tends to intensify this effect, further increasing operational costs.

To address this scenario, we propose implementing a solution that integrates device commercialization with a qualified sales strategy. Additionally, we suggest adopting a monthly subscription model for the service, based on the studies conducted on the house model, allowing for a more predictable and stable revenue stream.

Table 8 offers an alternative to address the recurring costs associated with devices by proposing the adoption of monthly plans tied to the different types of homes outlined in this study. These plans are designed as the financial component of an integrated solution aligned with the concept of a smart home, creating a sense of added value for the end customer and encouraging subscription to a monthly plan.

From the provider's perspective, this approach fa-

Table 8: Suggested Plans and Simulation.

Suggested Plans	
Device Range	**Price (USD)**
Between 1 and 15 Devices	$ 7.20
Between 16 and 40 Devices	$ 16.00
Between 41 and 65 Devices	$ 32.00
Between 66 and 100 Devices	$ 59.80

Plan Simulation				
Model	**Distribution**	**Operation Cost (USD)**	**Revenue (USD)**	**Profit (USD)**
House 1	100,000	$ 1,143,800.78	$ 1,599,800.00	$ 455,999.22
House 2	100,000	$ 2,111,574.52	$ 3,199,800.00	$ 1,087,225.48
House 3	50,000	$ 2,014,797.15	$ 2,990,000.00	$ 975,202.85
Starter Kit	250,000	$ 1,143,800.78	$ 1,799,500.00	$ 655,699.22
Total	500,000	$ 6,413,973.24	$ 9,589,100.00	$ 3,175,126.76

cilitates the management of ongoing messaging costs, which are incurred regardless of new sales. For the end customer, the plan goes beyond the mere purchase of a device, offering an additional solution that enhances both functionality and value. In this way, the subscription model not only fosters customer retention but also provides a recurring revenue stream, increasing the financial predictability of the operation.

In this simulation scenario, we projected the distribution of 500,000 smart homes in the suggested models to estimate total operating costs. We then designed monthly subscription plans based on the range of devices corresponding to the home models used in this study. With the projected distribution in place, we calculated the monthly revenue from these subscriptions. At the end of the process, we determined the difference between the projected subscription revenue and the total monthly costs, providing insight into the profitability of the distribution. In addition, we outlined a scenario for supplemental profitability, which could offset recurring operating expenses if sales volume stabilized over time. Below, we detail the steps taken to perform these calculations, providing clarity on the underlying assumptions, methods, and results.

Equation 6 calculates the operational costs based on the distribution of different home models. For example, for Model 1, we assigned a distribution of 100,000 units, and the equation computes the associated costs for this quantity and type of home.

$$\text{Cost\_P\_Dist} = \text{Mess\_Cost} * \text{Q\_Houses\_Dist} + \text{Cost\_Cloud} + \text{Cost\_OPEX\_Empl} \quad (6)$$

Where Cost_P_Dist represents the total monthly cost per residential model, Mess_Cost refers to the total recurring cost of messages per residential model for the month. Q_Houses_Dist refers to the universe of smart home distribution for the study model, while Cost_Cloud is the value associated with the cloud servers that support this large-scale operation. Finally, Cost_OPEX_Empl corresponds to the labor cost required to maintain this operation on a monthly basis.

Equation 7 The revenue is calculated based on the distribution of different smart home models. For example, Model 2 has a distribution of 100,000 units, and the equation multiplies this quantity by the suggested plan price to determine the total revenue for that model.

$$\text{Reven\_P\_Dist} = \text{Q\_Houses\_Dist} * \text{Price\_Plan\_Model} \quad (7)$$

Where Reven_P_Dist represents the total monthly revenue per residential model, Q_Houses_Dist refers to the distribution universe of smart homes for the study model, while Price_Plan_Model is the value associated with the suggested monthly subscription per residential model.

Profitability, as shown in Equation 8, is also determined based on the distribution of different smart home models. It is calculated by finding the difference between the total revenue generated and the associated distribution costs

$$\text{Profit\_P\_Dist} = \text{Reven\_P\_Dist} - \text{Cost\_P\_Dist} \quad (8)$$

Where Profit_P_Dist represents the total monthly profit per residential model.

Finally, the total values of operating costs, revenue, and profitability are calculated. These metrics are represented by the equations 9, 10, and 11, respectively. In this context, Total_Operation_Cost corresponds to the accumulated operating cost of the entire scenario, Total_Revenue represents the total revenue generated by the distribution of smart home models, and Total_Profit reflects the net profitability, calculated as the difference between total revenue and operating costs. These calculations provide a comprehensive financial overview, allowing the assessment of the sustainability of the business model and guiding the provider for strategic decisions.

$$\text{Total\_Operation\_Cost} = \sum_{i=1}^{n}(\text{Cost\_P\_Dist}_i) \quad (9)$$

$$\text{Total\_Revenue} = \sum_{i=1}^{n}(\text{Reven\_P\_Dist}_i) \quad (10)$$

$$\text{Total\_Profit} = \sum_{i=1}^{n}(\text{Profit\_P\_Dist}_i) \quad (11)$$

5 CONCLUSION AND FUTURE WORKS

To enable an affordable transition from conventional to smart homes, the introduction of a new key player, the smart environment provider, is essential. This entity is responsible for delivering and managing smart applications that control household appliances and devices, ensuring an integrated and seamless experience for users. The analysis in this study highlights that even the most advanced packages proposed are more cost-effective than those presented in previous research, offering a sustainable and advantageous solution.

Additionally, our study explored subscription models as an alternative to the traditional device sales model, demonstrating the feasibility of a monthly subscription-based approach. The research showed that this model can foster greater customer retention, financial health, and scalability for smart service providers. Future work will focus on optimizing the cloud infrastructure needed to efficiently support these services and further refining the transition process, ensuring that smart solutions are accessible to consumers with diverse profiles and economic backgrounds.

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