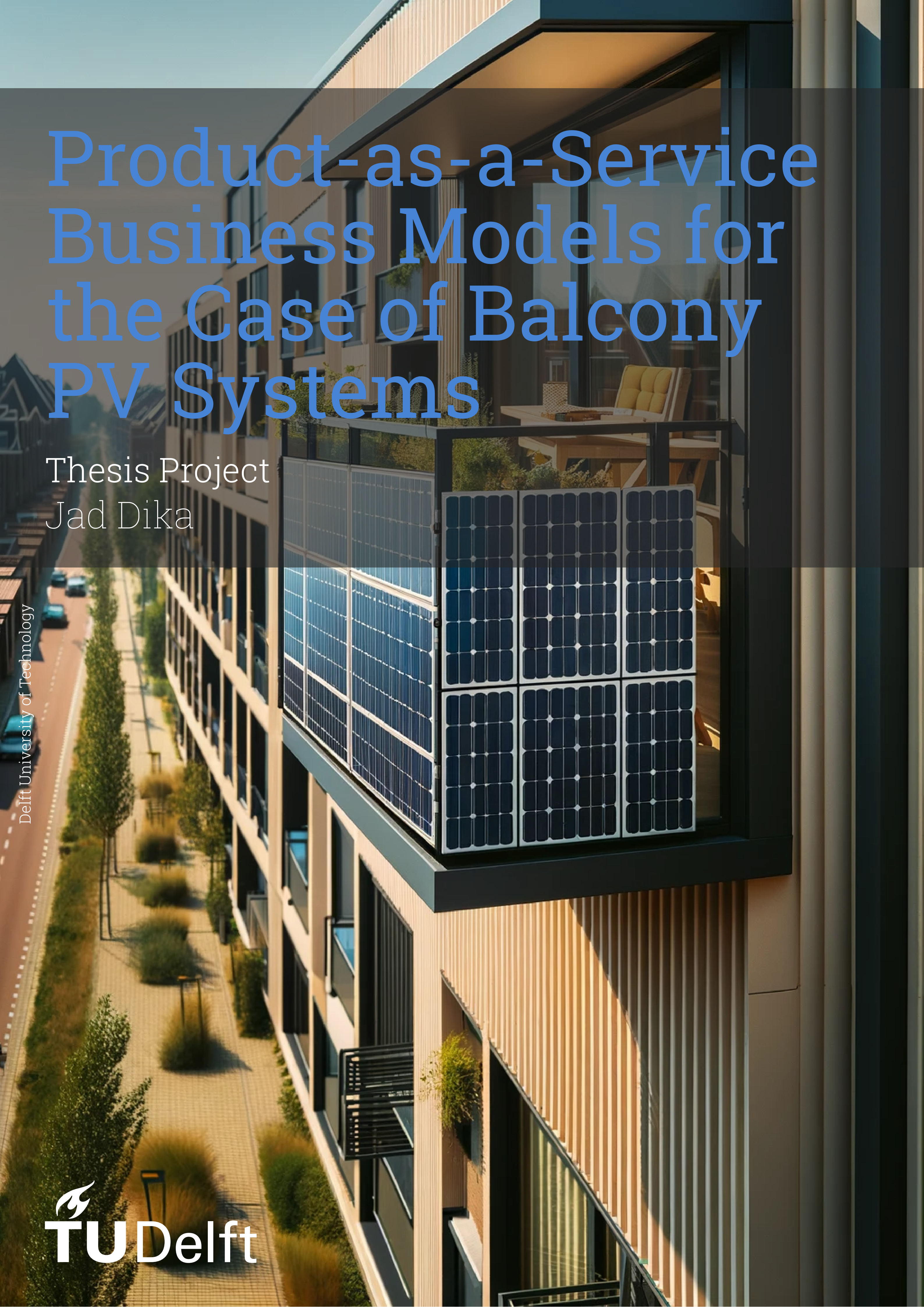

Product-as-a-Service Business Models for the Case of Balcony PV Systems

Thesis Project

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Delft University of Technology

TU Delft

Product-as-a-Service Business Models for the Case of Balcony PV Systems

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Abstract

The full potential of the Dutch residential solar sector is still untapped, as renters face barriers to the adoption of solar PV systems. These barriers are caused by the mismatch between the PV panel lifespan and the rental contract period of rental properties. This thesis studies the implementation of a product-as-a-service business model for the case of balcony PV systems. By virtue of its flexibility, the business model allows tenants to consider solar energy solutions, hence expanding the residential solar PV market. In addition, the business model applies strategies designed to enhance its circularity, which in turn contributes to enhancing the circularity of the Dutch PV sector. Numerous concepts were developed and evaluated to decide on the winning concept, which consists of a compact, modular PV system that can be easily installed on a wide range of balconies while preserving their aesthetics and offering an optional privacy feature. The business model proved to be profitable for both the company and the end-users, with an Internal Rate of Return (IRR) in the range of 6.1 and 7.6% and cost savings ranging between 12 and 17 €/year. From an environmental perspective, electricity generated under this business model was found to have an 80% lower carbon footprint than the electricity drawn from the grid. Ultimately, this research offers interested stakeholders a blueprint for a novel application of the product-as-a-service business model, that if put into practice can accelerate the adoption of solar PV solutions.

Contents

List of Figures

List of Tables

Nomenclature

Abbreviations

Abbreviation	Definition
PaaS	Product-as-a-Service
LCOE	Levelized Cost of Electricity
CAPEX	Capital Expenditures
OPEX	Operational Expenditures
NPV	Net Present Value
IRR	Internal Rate of Return
MP	Market Price
PF	Profit Factor
SFu	Unadjusted Subscription Fee
CSu	Unadjusted Cost Saving
Pu	Unadjusted Profit
SFa	Adjusted Subscription Fee
CSa	Adjusted Cost Saving
Pa	Adjusted Profit
BPV	Balcony PV
PPV	Portable PV

1 Introduction

1.1. Background and motivation

The Netherlands is in the midst of transitioning from a fossil fuel-based energy system to one that relies mainly on renewable energy sources. This comes as an endeavor towards reaching the country's national and international targets of reducing greenhouse gas emissions by 55% in 2030 compared to the 1990 levels, and becoming carbon neutral by 2050 as agreed on in the Paris Agreement and the European Green Deal [80] [20] [14]. To achieve these goals, The Netherlands must accelerate the pace of renewable energy adoption.

The Dutch solar PV sector is a key component of this transition as it accounts for 37% of renewable electricity generated in the country [127]. This sector has been growing significantly in recent years, with a total installed capacity of 23.9 GW in 2023 compared to only 4.61 GW in 2018 [128]. Even though the growth in the solar PV market seems promising, the current pace is not sufficient to reach the ambitious targets set by the government [129]. Consequently, more effort is needed to accelerate the growth of solar PV capacity.

This thesis comes as an attempt to contribute to the development of the solar PV sector. It seeks to do so by first identifying the main challenges and barriers to the sector's growth, to later proposing a business solution designed to increase the adoption of solar PV technology.

1.2. Problem statement

While solar PV adoption is soaring in the Dutch residential sector, one particular subsector lags well behind others. In fact, the tenants of rental properties which constitute 4 out of 10 of properties in the Netherlands face significant challenges installing PV systems [126]. These challenges are mainly due to restrictions imposed by rental contacts. Indeed, there is a significant mismatch between the lifespan of a typical solar system and the average period of (fixed-period) rental contracts, making them reluctant to commit to long-term PV installations. Moreover, the landlord might impose restrictions on such installations, and obtaining his consent constitutes an additional hurdle for tenants. Consequently, as long as these barriers exist, the full PV adoption potential of the Dutch residential sector will remain untapped. Hence, there is an urgent call to find solutions that would make PV technologies accessible and economically attractive to the tenants of rental properties, apartments in particular.

1.3. Proposed solution

This thesis proposes a potential solution to the aforementioned problem. The solution consists of a balcony PV system offered to clients under a Product-as-a-service (PaaS) business model. The system is both compact and lightweight, meaning that it can be easily installed on even the smallest of balconies, thereby addressing space limitation issues. Moreover, the PaaS scheme allows customers to lease the PV system, while it is installed on their balconies, for a specified period of time in return for a subscription fee. This effectively eliminates the need for an initial investment which might discourage rental property tenants. By implementing these measures, the suggested business model attempts to tap into an untapped segment of the residential PV market, allowing rental apartment tenants to participate in the renewable energy transition and save on their electricity bills. Additionally, by applying circular economy strategies designed to maximize the lifetime of the offered system, the business model contributes to boosting the circularity of the PV industry.

1.4. Thesis aim and research questions

This thesis aims to develop a Product-as-a-service (PaaS) business model for balcony PV systems in The Netherlands and to assess its financial viability and circularity. To that end, the thesis seeks to answer the following main research question:

"How can the Product-as-a-Service business model for portable PV systems be profitably applied to encourage the adoption of solar PV among renters with short-term contracts while boosting the circularity of the Dutch PV sector?"

This primary question is further explored through the following sub-questions:

- What are the primary needs, and requirements of the primary stakeholders involved in this business model?
- Who represents the primary target segment for this business model?
- What variety of business models are applicable to portable PV systems, and which model has the highest chance of success?
- What are the defining specifications of the PaaS business model for portable PV systems?
- What financial incentives and pricing structures can be integrated into the model, and what are the observed financial outcomes?
- What business strategies can be employed to maximize the lifetime of portable PV systems under the PaaS business model?
- How can the application of the PaaS model be financially viable and competitive in the current market for portable PV systems?
- What is the environmental impact of this business model, and how does it contribute to the circularity of the Dutch solar sector?

1.5. Research significance

This thesis contributes to the renewable energy transition by offering energy companies and investors a blueprint for a novel application of the product-as-a-service business model. When put into practice, the business model would facilitate the adoption of PV systems in a new market segment, consisting mainly of rental apartment tenants. Consequently, the new customer segment is allowed to save on their energy bills while participating in the energy transition. Additionally, this work adds to the body of knowledge in the field of circularity and sustainability by incorporating circular business strategies in the domain of renewable energy, especially in the solar energy sector. Finally, this study could help inform policymakers to set regulations that support sustainable energy practices and business innovations.

1.6. Thesis outline

This thesis report is structured as follows. Chapter 2 presents the methods and tools employed to acquire the necessary data to address the research questions and objectives of the project. The problem is further explored by conducting a stakeholder and market analysis to identify the stakeholders' needs and preferences along with external factors affecting the market, as discussed in chapter 3. After exploring the problem, the scope of the project, the target audience, and the design directions are identified in chapter 4. Once the problem is defined, the ideation phase takes place in chapter 5, where numerous PaaS concepts are generated based on the previous design directions. In the same chapter, the concepts are evaluated against a set of criteria to determine their feasibility and effectiveness and select the final concept. Next, in chapter 6, the product specifications are selected along with the cost structure and electricity yield of the system. In addition, a suitable pricing scheme is selected and the contract specifications are outlined. Afterward, a detailed financial analysis is conducted to assess the financial viability of the final concept in chapter 7. To test the success of the business model from the perspective of potential end-users, a market evaluation was conducted in chapter 8, where points of concern were gathered, and improvement points were proposed. The environmental impact of the final concept is also assessed in chapter 9 by computing the carbon footprint and energy payback of the business model, in addition to suggesting business strategies to extend the lifetime of the system. Finally, in chapter 10 the conclusion is presented to summarize the key findings of the study, indicate the significance of the study, and offer recommendations for further research.

2

Methodology

In this chapter, the methods and approaches employed for collecting and analyzing data are explained while indicating their relevance to addressing the research questions. The tools employed for the double diamond are discussed in section 2.1. Next, the pricing scheme model and financial assessment techniques are presented in section 2.2. Afterward, the procedure for assessing the environmental impact of the business model was discussed in section 2.4. Finally, the market evaluation procedure is explained in section 2.5.

2.1. Double Diamond Model

The double diamond model was utilized in the first stage of this project to identify and define the problem and then develop numerous solutions and evaluate them to finally deliver the final concept. This model is made up of two diamonds: the problem space and the solution space. Each of these diamonds has a diverging and converging process. For example, the first diamond representing the problem consists of a diverging part "Discover", where an understanding of the problem under study takes place. Next, the diamond converges to the defining part where the problem, target segments, and goals and requirements are presented. Once the problem is defined at the intersection of the two diamonds, the model diverges in the development part to develop multiple concepts and solutions. Finally, the model converges into the delivery part, where the concepts are evaluated to select a final winning solution. For each of the four sections, different methods and tools are employed as indicated in Figure 2.1.

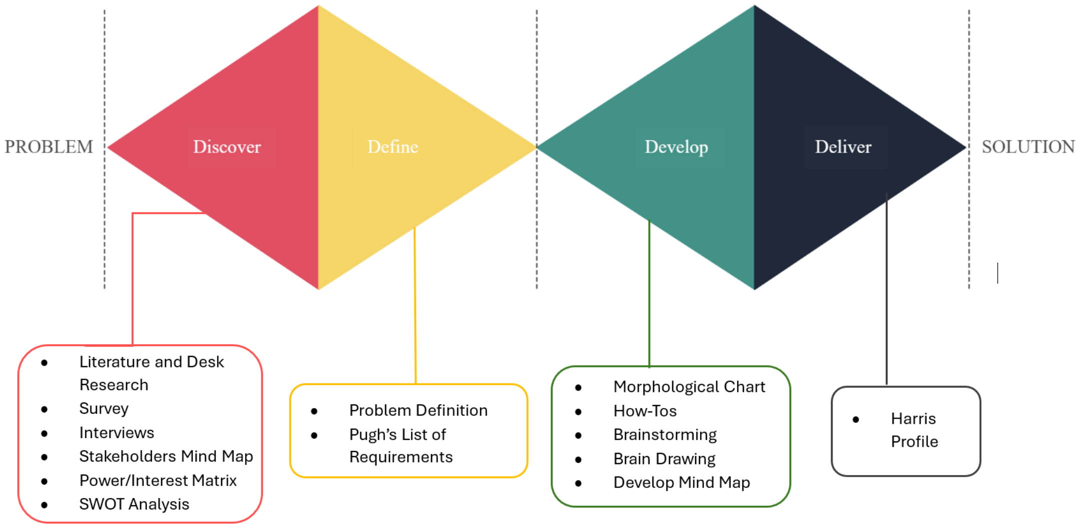


Figure 2.1: Double Diamond Model

2.1.1. Discover Phase

The first stage in the double diamond is the discover phase. In this phase, the goal is to diverge in identifying and understanding the problem. This involves conducting literature and desk research, identifying and categorizing the stakeholders, in addition to conducting surveys and interviews to understand their needs and concerns. Moreover, this phase is intended to collect a wide range of information and data about the market dynamics and the external factors potentially causing threats or opportunities.

Literature Review & Desk Research

To discover the problem, literature, and desk research were performed to acquire an understanding of the trends and developments in the Dutch residential PV sector, the circularity of the solar industry, the product-as-a-service business model, and portable PV systems.

Survey

A survey targeting potential customers was conducted to obtain quantitative data that helped segment the residential solar PV market and understand public perceptions toward the use of portable solar PV under the PaaS business model. Forty-six people belonging to diverse adult group ages participated in the survey. These participants were asked questions about their demographics, motivations for adopting solar PV systems, and environmental interests. In addition, the PaaS business model and portable PV systems were introduced and participants were asked to select the most desirable features they prefer, alongside their past leasing experiences. The questions of the survey are stated in Appendix A. The survey was conducted both online, via LinkedIn, and in person across the Netherlands, targeting a diverse demographic. The selection aimed at ensuring a broad representation of views from varying ranges of respondents in terms of types of residence, regional origins, ages, and marital and family statuses. The results of the survey were discussed in the consumer analysis chapter 3.3.3.

Interview with Consumers

To gain qualitative data about the subject under study, a total of six interviews were conducted with tenants. The interviews were performed to gather their preferences and concerns related to the business model and identify the different features potential customers look for in a similar business model. The participants were also asked about their previous leasing experiences. The questions of the interview are indicated in Appendix B. The selection process took place in the city of The Hague (between 13 and 17 March 2024) where I visited multiple properties with balconies and interviewed the tenants at their place. The results of the interview are discussed in the consumer analysis chapter 3.3.3.

Interview with an expert from Zelfstroom

Aside from end-users, an expert from the service company Zelfstroom, the company was introduced in 3.3.2, was interviewed to help learn about consumer behavior under the PaaS business model, the competitors present in the market, the pricing and contract features adopted by the company, and multiple other questions indicated in Appendix C. Another interview was scheduled with a company offering balcony PV solutions, however, the meeting did not take place because of the tight schedule of the experts in the company.

Stakeholder Mind Map

The stakeholder mind map method was used in section 3.2 to map out the complex interactions of the stakeholders within the project and present the relationships and exchanges between them. Hence, clarifying their roles and the type of their collaborations. The map also categorizes the actors into primary, secondary, and tertiary groups based on their influence on the project outcomes. In addition, the nature of their connections was sorted into four types: transfer of information, goods and services, financial transactions, and permissions.

Power/Interest Matrix

In the stakeholder analysis, the power/interest matrix was used to classify all the actors with a vested interest in the activities and decision-making of the PaaS balcony PV business model. The method consists of power and interest axes, indicating the level of power and interest these stakeholders have in the proposed business model. These axes form four main quadrants: low interest/ low power, low interest/ high power, high interest/ low power, and high interest/ high power. Identifying the category of each stakeholder allows each of them to be effectively managed throughout the project.

SWOT Analysis

The last tool in the Discover section is the SWOT Analysis. This tool was used to analyze the strategic position of the company offering the PaaS business model. The SWOT analysis indicates the strengths and weaknesses of the company along with the threats and opportunities imposed by the market in which this company operates. This tool was used to position the service company in the market with its competitors. Hence, allowing the service company to recognize the type of innovations that can be implemented to increase the chances of success.

2.1.2. Define Phase

After gaining an understanding of the problem at hand, the model converges to the define phase, where the problem is narrowed and defined. In this phase, the target segment is selected and the main goals and design directions are established. Here, Pugh's list of requirements was employed to determine the key requirements to achieve these goals.

Pugh's List of Requirements

To define the goals and requirements of the project, Pugh's list of requirements was utilized in chapter 4. This method identifies all the design objectives and important functional and non-functional characteristics to ensure a successful design. Hence, it allows the project to maintain focus on the necessities of the system to meet its intended objectives while ensuring its alignment with the project goals.

2.1.3. Develop

Once the problem, goals, and design directions are defined, the idealization and conceptualization processes take place to generate a range of ideas and solutions. This phase involves brainstorming, drawing, and the use of other techniques such as morphological charts, How-Tos, and mind maps to generate a wide variety of ideas.

Develop Mind Map

To develop concepts and solutions, the mind map indicated in Appendix G.1 was used. To develop this mind map, a combination of multiple other methods were used, which are brainstorming, brain drawing, morphological chart, and how-to questions. First, the morphological chart alongside the how-to questions was used to generate ideas based on the deconstruction of the overall function of the product offered into sub-functions. These sub-functions describe the characteristics that the product should possess to service its overall function and purpose. Then, multiple solutions for each sub-function were generated using the drawing and sketching methods that allowed the generation of numerous ideas for each sub-function. Consequently, the combination of a solution from each sub-function resulted in the creation of multiple concepts, as indicated in the mind map figure in Appendix G.

2.1.4. Deliver

The model converges in the deliver phase to evaluate the previously generated concepts based on the design criteria determined in the define stage. Multiple evaluation methods exist, however, the Harris Profile evaluation tool was selected as it allows for a clear graphical representation of each concept.

Evaluating the developed concepts allows the optimal concept or a combination of concepts to be selected as the winning final design.

Harris Profile

After multiple concepts were generated using the mind map method, the Harris Profile tool was utilized to evaluate these concepts. This tool serves as a visual representation of the strengths and weaknesses of each of the generated concepts according to pre-defined criteria. Hence, this allows the concepts to be evaluated by comparing the strengths and weaknesses of each suggested concept. It is important to note that these criteria are ranked in order of importance based on the findings of the consumer and competitive analysis. This means that the most important criteria are mentioned first and the least important last. The Harris Profile then examines how each concept meets the listed design requirements on a 4-point scale as indicated by figure 5.6. The minus signs indicate bad or moderate performance, and the plus signs indicate a good or excellent score. This method was used to evaluate the developed concepts and select a final solution.

2.2. Final Design

Having selected the final concept, its product specifications are determined. Next, the cost structure covering both capital and operational expenditures is determined. Subsequently, the electricity yield is computed to determine the levelized cost of electricity in the business model. Based on these findings, the pricing scheme model covering the subscription fees, cost savings, and profitability is developed.

2.2.1. Cost Structure

After selecting all the specifications of the final concept, the cost structure was estimated. This cost structure consists of two categories, capital expenditure (CAPEX) which refers to the costs of acquiring the companies' assets, and operational expenditures (OPEX) representing the ongoing day-to-day costs of running the business model. To simplify these calculations, all costs were considered per unit of the offered product. The results of this section are indicated in section 6.4.

2.2.2. Electricity Yield

Next, a crucial step was to estimate the electricity yield of each subscription, as it affects the LCOE of the system. The electricity yield was calculated by computing the irradiation [kWh/m^2] on the tilted surface. The values were calculated using SolCast and Meteonorm software to ensure the integrity of the results. The software used the location, tilt of the panel, and orientation as inputs and returned the total irradiance hitting the panel for every hour of the year as output. The sum of the total irradiance for the whole year provided the total electricity generated per one meter squared for each panel since each has a specific tilt and surface area. For the sake of simplicity, all apartments were assumed equally likely to be oriented in the three orientations (South, East, and West) and that most balconies have a better orientation than North. In the case where an apartment has a North orientation only, then it was found not profitable to subscribe to the service. Hence, the weighted average electricity yield of each system was calculated using the equation 6.3. The resulting electricity yield was multiplied by the efficiency of the panel, micro-inverter, cables, performance ratio, and shading factor, as indicated in equation 9.3. Moreover, the degradation of the panel throughout the years was considered, ensuring realistic and accurate electricity yield results. The assumptions for calculating the electricity yield and the results are shown in section 6.4.

2.2.3. Levelized Cost of Electricity (LCOE)

After determining the cost structure and electricity yield for every year of the period, the levelized cost of electricity (LCOE) was calculated. This metric calculates the cost of generating one unit of electricity for a specific energy-generating unit, usually expressed in €/kWh. The LCOE equation calculates the initial capital, operations, and maintenance costs over the expected lifetime of the system. These costs are then divided by the electricity yield forecasts over the same period while accounting for the time value of money and the degradation of the PV panel. This method is a crucial metric to assess the cost-effectiveness of the final design and is used as input for the calculations of the pricing scheme. The LCOE equation, calculations, and assumptions made are indicated in Appendix E.

2.2.4. Pricing Scheme

Once the LCOE of each subscription was computed, the pricing scheme model was developed. First, the subscription type was determined by comparing two types of pricing strategies: ”Fixed” and ”Per-kWh”. Next, a model consisting of three sub-models was developed. The model takes as input the wholesale market price of electricity, profit factor, subscription type, and age of the panel and returns the subscription fee, cost savings, and profit of the total or kWh values, based on the preference of the stakeholder. The first sub-model ” Unadjusted Pricing” does not account for the degradation of the panel in the outputs. To account for this degradation, a second sub-model was designed where the adjusted subscription fee, cost savings, and profit are issued per kWh. Finally, an optional step is the third sub-model ”Final Pricing” which returns the total subscription fee, cost savings, and profit when provided with the actual electricity yield. The whole pricing scheme model is explained in detail in section 6.6. Moreover, the contract specifications of the business model were formulated in section 6.7.

2.3. Financial Assessment

To assess the financial feasibility of the business model, a financial assessment was conducted from the perspective of two primary stakeholders: the company adopting the business model and the potential end-users subscribing to it.

2.3.1. Company Perspective

From a company’s perspective, the essential financial metrics used are the following:

1. **Net Present Value:** This metric calculates the difference between the present value of future cash inflows and the initial investment, as indicated by the equation in Appendix H. Hence, this tool helps determine if the project will generate returns that exceed the initial investment while considering the time value of money. A positive NPV reflects that the project adds value to the company adopting it, suggesting a profitable business model. The main disadvantage of this tool is that it is subjective to the discount rates selected, which can significantly impact the decision-making process.
2. **Internal Rate of Return (IRR):** The IRR is the discount rate for which the previously discussed NPV equals zero, as shown in Appendix H. This metric provides the expected rate of return from a project, meaning that a higher IRR indicates a more attractive investment opportunity. The IRR is usually benchmarked with the cost of capital specified by each company. In practice, if the IRR exceeds the Weighted Average Cost of Capital determined by the company, it is considered a financially viable project to adopt. It is worth mentioning that this tool can be misleading when comparing different projects as some projects can have multiple IRR values, making it difficult to recognize the right return of the project.
3. **Payback Period:** The payback period computes the time it takes for the project’s cash inflows to cover the initial cost of investment, as explained in Appendix H. Hence, the shorter the payback period, the faster the company covers its costs and eliminates the uncertainty associated with the project. The payback period is computed by generating a cumulative cash flow that subtracts the cash inflows from the initial investment and identifies the year at which this cumulative cash flow reaches a positive value. The limitation of this metric is that it ignores the time value of money and cash flows beyond the payback period.
4. **Discounted Payback Period:** This metric is the same as the payback period tool described above, however, this time the time of the value of money is taken into consideration by calculating the discounted cumulative cash flow of the project and identifying the year at which the company covers its costs. In the final concept section, the LCOE, subscription fee, and cost structures

were calculated. These findings were used to generate an estimation of the net cash flow of the company adopting the business model. To minimize uncertainty, the net cashflows were first generated per subscription or unit for each of the two subscription types. The net cash flow was computed by subtracting the revenues generated by the subscription costs from the cost structure of the respective subscriptions over 25 years.

2.3.2. End-User Perspective

From an end-user's perspective, the main metric used to represent the attractiveness of the business model for end-users is the cost savings. In addition, other non-monetary values are gained by subscribing to the business model which is discussed in Chapter 7.

2.4. Environmental Impact Assessment

To assess the environmental impact of the business model, the carbon footprint and energy payback period were calculated. First, the embodied energy of producing the components of the product, in addition to transporting and maintaining it was determined. This allowed the calculation of the energy payback time using equation 9.1. This value was then compared with that of the rooftop PV system to serve as a reference. After determining the energy payback time, the carbon footprint was computed. This was done by estimating the carbon emissions [g CO_2e] of each of the previously mentioned components and processes as a function of the PV panel's emissions (per kWh of rooftop PV yield), using equation 9.2. Next, the obtained value was multiplied by the total electricity yield of the rooftop PV system. The resulting value was then divided by the electricity yield of each subscription plan to obtain their total carbon footprint. The total carbon footprint of each business model was then benchmarked to the carbon footprints of a regular rooftop PV system and that of the electricity grid.

2.5. Market Evaluation

To evaluate the attractiveness of the developed business model, a total of five end-users were interviewed. Three of these end-users already participated in the interviews from the consumer analysis part. These interviews were performed to gather qualitative data about the interest of end-users to subscribe to the final design of the business model. In addition, interviewees were asked about their points of concern and suggestions to ameliorate the design. The selection process took place in the city of The Hague (between 16 and 30 June 2024) where I visited multiple properties with balconies and interviewed the tenants at their place. The results of the interview are discussed in chapter 8.

3

Discover

This chapter presents the Discover phase of the Double Diamond design model which serves as the first exploration stage of the problem by providing insights and a better understanding of the problem posed. This phase involves conducting a literature review to explore the aspects of the Dutch residential solar PV sector, the circularity and application of the PaaS business model within the solar PV energy field. In addition, the chapter conducts a stakeholder analysis, as presented in section 3.2, where the key stakeholders are identified, along with their preferences, needs, and concerns. Additionally, a market analysis is conducted in section 3.3 to understand the dynamics, threats, and opportunities of the residential sector market, by understanding the regulatory, economic, social, and technological influences.

3.1. Literature review

This literature review explores the aspects of the Dutch residential solar PV sector. Focusing on key trends and developments, the concept of circularity, and the application of the Paas business model within the solar energy industry. In addition, the section introduces the concept of portable PV indicating its main advantages when compared to regular PV systems.

3.1.1. Trends and developments in the dutch residential PV sector

In this section, the focus is on studying and understanding the dynamic setting of the Dutch residential solar PV industry. Consequently, the latest trends and developments shaping the residential solar PV sector are explored. In addition, the challenges to the adoption of solar PV systems by households in the Netherlands are discussed to finally introduce the diverse existing solutions employed to address these challenges.

Growth and Developments

Over the past decade, the total installed capacity of residential solar PV in the Netherlands increased from 0.182 GW in 2012 to 4.95 GW in 2021 [59]. Additionally, the Netherlands deployed 2 GW additional solar systems in the residential sector in 2022 [16]. Furthermore, in 2022, the Netherlands witnessed a historic increase in the residential rooftops solar PV capacity with an added 1.8 GW, marking a 38% increase compared to 2021 [57].

Barriers to Adoption

Numerous challenges and obstacles affect the large-scale integration of residential PV. For example, a study conducted by the United Nations for Climate Change (2023) showed that 43% of Dutch households are unable to install solar panels because they live in apartments or rental properties [139]. In addition, another study showed that less than one percent of Dutch apartments are equipped with PV systems due to shared roofs and the lack of installation space [68]. Aside from these barriers, the high upfront cost of PV systems was shown to play a crucial role in the adoption of the technology [107]. Additionally, the absence of after-sale services such as consistent maintenance, and monitoring offered by energy companies showed hindering in the employment of PV systems in households [6] [65] [29]. Moreover, the new decision to abruptly phase-out the net metering scheme in the country is expected to affect the attractiveness of PV systems [66]. Consequently, to accelerate PV market growth, especially in the residential sector, the above-mentioned barriers should be surpassed.

Existing Strategies and Solutions

To address these problems, multiple solutions have been proposed by energy companies, the government, and other players. The proposed solutions are:

1. **Portable PV panels** Portable PV systems were introduced by numerous solar manufacturers and energy companies. These portable devices allow people living in apartments and rental properties to install movable solar panels on their balconies above their windows and even on the roofs of their buildings [90]. These systems can be installed and removed easily, therefore solving spatial limitations and contract period issues. These systems allow renters to move the technology to their next property at the end of the rental contract period.
2. **Community Solar** For tenants living in apartments or rental properties, joining a community solar project is another way to support the generation of clean energy and save money on electric bills without installing solar panels on individual dwellings [141]. Community solar projects are large solar power plants that generate electricity and supply it to the utility grid. In this case, the customer willing to use clean energy generated by solar panels subscribes to his utility's solar farm by paying a monthly fee and is assigned a share of the farm. This share of solar energy generated is then supplied to the utility grid. The utility company pays the community solar provider for the energy generated by the farm. The subscribers receive part of this payment as credits that they can apply to lower their monthly electricity bills [35]. Figure 3.1 presents a visual description of the community solar scheme. Aside from offering cheaper clean energy without the need for installation space, community solar has multiple drawbacks related to opposition by surrounding communities concerning aesthetic, economic, and environmental effects on the direct environment [62]. Additionally, community solar power plants are not available in all regions, therefore access to such projects can be limited.

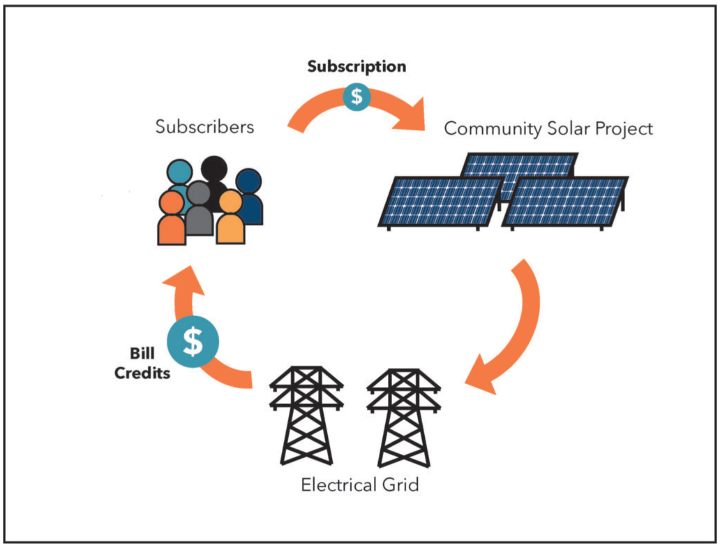


Figure 3.1: Community Solar System [70]

3. **Solar Green Leases** A green lease is a type of agreement between the landlord of the building and the tenant to enhance the energy efficiency and eco-friendliness of the property. This type

of lease solves the problem of split incentive, where the tenants are often reluctant to invest in solar systems for buildings they do not own and landlords are hesitant to spend money on improvements for a property they do not use. Hence, solar green leases help the two actors to meet in the middle to cooperate and agree on meeting and performing environmentally friendly practices [8]. For example, in the case of solar systems, the landlord can provide the financing for the solar system and hence enhance the value and appeal of the property, increase the rent of the property, or even reduce utility bills in cases where the landlord is responsible for them. In return, the tenant can use clean electricity without the need to pay or install a solar PV system and reduce their electricity bills.

3.1.2. Circularity in the Solar Energy Industry

As the world seeks sustainable solutions for the future, circularity evolved as a concept that addresses the efficiency of energy-generating solutions and their environmental impact. In this section, the focus is on the concept of circularity within the solar energy field and the current state of circular practices and goals in the Netherlands. In addition, the section also explores different circular business strategies that can be adopted by companies and other actors.

Circularity Concept Definition

The growth in demand for solar PV in the coming years will result in the disposal of vast amounts of waste. In fact, the accumulation of photovoltaic (PV) waste is on the rise and is expected to keep increasing. It is forecasted that by 2030, this accumulation will amount to between 1.7 to 8 million tons of waste. By 2050, total waste is projected to reach 60 to 78 million tons [46].

Here comes the importance of the photovoltaic (PV) circularity concept, where the lifecycle of solar panels is managed to maximize resource efficiency in addition to minimizing waste and environmental impact. This includes designing for longevity, investigating module remanufacturing, enhancing closed-loop module recycling, and ensuring that end-of-life panels are handled in a way that reduces environmental impact as indicated by Figure 3.2 and article [52]. Therefore, circular economy approaches can mitigate material requirements and contribute to more resilient supply chains [52]. In other words, the circularity concept suggests strategies to make PV an entirely sustainable energy source [24].

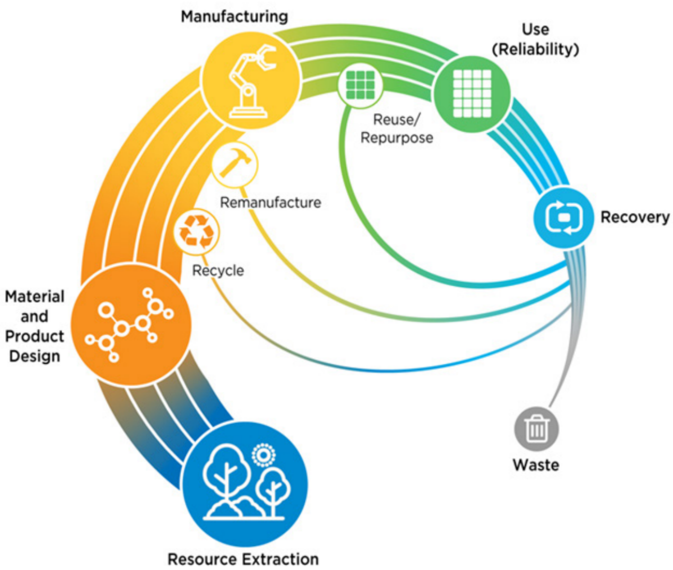


Figure 3.2: Circular Economy for PV System Materials [24]

The circularity concept can be applied in practice through the design and implementation of circular business models. These business models are recognized as accelerators for the circular transition due to their ability to promote intelligent product design and resource efficiency. As highlighted by Bocken et al. (2016), these models help extend the life and reuse of products and help capture the remaining value from by-products or 'waste'. The objective of these models is to preserve the products for the longest period possible to minimize environmental impacts and resource extraction.

Circular Business Strategies

Offering a PaaS incentivizes companies adopting the business model to maximize the lifetime of their products as this would mean a lesser necessity to replace the system and consequently higher long-term returns and profits. This action not only benefits businesses but also extends the product's lifespan means that more people will benefit from the same system and hence minimizes the demand for new products. This in turn minimizes the need to extract new raw materials to manufacture new products, therefore lowering the material footprint of the business model. There exist numerous business strategies that companies can rely on to extend the lifetime of products:

1. **Design for Durability**

   The first stage focuses on the design of the product by ensuring that the product relies on a durable and modular design. Designing a product for durability ensures that the mechanical design and the materials used are picked carefully to ensure the design can withstand frequent installation and removal and harsh weather conditions. For example, selecting high-quality and durable solar panels with a low degradation factor and higher lifespans from a reputable manufacturer guarantees better performance over time and longer longevity. In addition, another crucial step in the design of the system is to ensure a modular design that reduces the complexity of assembly and disassembly, as this helps facilitate the process of repair, remanufacturing, and other strategies that will be discussed in more detail in this section.
2. **Reuse**

   The main idea of the PaaS business model is to allow tenants with short-term contracts to access solar solutions without having to worry about buying the system. After these customers are done using the system, other customers can subscribe and lease the product. Hence, this business model relies on the reusability strategy of balcony PV systems by multiple end-users which under consistent repair and maintenance services can help satisfy the demand of a large portion of customers. This ensures that the system does not go to waste when customers are done using it, consequently extending the lifetime of the system.
3. **Repair**

   Offering regular maintenance and repair services for damaged or broken components to guarantee that the system is working properly and efficiently can also help extend the lifetime of the system and avoid waste by renewing it instead of directly taking it out of circulation. For example, throughout the lifetime of the panel, microcracks and hotspots can appear at the surface which can cause the glass to flake, lowering its moisture and water resistance. Noticing and fixing these problems can be challenging for customers and often require professional maintenance from experts.

Additional circular business strategies involve remanufacturing, repurposing, and refurbishing. However, the current practices and opportunities for adopting these strategies in the case of solar systems are limited. Other strategies such as recycling can be applied to the case of PV panels, however, these methods are currently not cost-effective, and not very common in the Netherlands. The current practices focus on recycling glass and aluminum only, excluding critical raw materials which are the most valuable. Consequently, further progress is required in the field to make recycling more attractive for companies to rely on. Therefore, these strategies are currently more challenging to apply and more effort should be made to help overcome these challenges.

Current State in the Netherlands

Considerable efforts are being invested to enhance the circularity of the PV sector in the Netherlands. For example, the SolarNL program which focuses on advancing solar PV technologies was awarded a grant loan to support the large-scale production of circular solar cells and panels in the Netherlands [119].

Furthermore, supplier Sungevity is working in collaboration with WEEE NL and Urgenda to launch Zon-Next which is a platform that matches supply and demand for refurbished panels [55]. Other companies such as Solarge are working on producing more circular solar panels by replacing glass and aluminum with synthetic recycled materials. This allows panels to be easily separated into solar cells that can be reused in other solar panels [55].

In addition, Biosphere Solar, a Dutch start-up is working on boosting PV circularity by designing modular solar panels that are easier to repair, upgrade, and refurbish. Hence extending the lifetime of solar modules and minimizing PV waste [113].

3.1.3. The Product-Service Business Model

In this section, the innovative Product as a Service (PaaS) business model is discussed. First, the definition, principles, and advantages of the PaaS model are portrayed in section 3.1.3. Next, the relation between PaaS and circularity is addressed in section 3.1.3. Finally, section 3.1.3 explores multiple applications of the PaaS business model within the solar PV industry.

Concept and Definition

The Product as a Service (PaaS) business model is a revolutionary model where customers are offered products and services under subscription models without getting ownership rights [61].

This model offers numerous benefits:

- Cost-Effectiveness: With various payment plan choices, customers can save money on their products [100].
- Flexibility: Clients can temporarily suspend subscriptions and change or reduce their services as needed [61].
- Customer Relationships: By more effectively satisfying customers' needs, the model enables businesses to build stronger bonds with them [100].
- Sustainability: Because the energy service companies still own the product in PaaS, they are encouraged to create long-lasting goods, easily maintained, and recyclable [61]. This point will be further discussed in section 3.1.3.

PaaS Business Model and Circularity

Throughout the previous years, producers and manufacturers relied on linear economy to sell their products. In this model, the products were sold in a one-time transaction. Next, after the product is bought, the customers become the owners and the producers/manufacturers are no longer responsible for providing care for the product. Hence, under a linear economy, there is no incentive for companies to enhance the lifetime of their products and their main goal is to sell as much as possible [94].

The reason behind this is that, when the service company is given responsibility for the usage and end-of-life stages of the product, there's a natural motivation to connect with manufacturers invested in extending the product's lifespans and durability. Hence, encouraging the creation of design decisions that support circular strategies like rethink, reuse, repair, re-manufacture, refurbish, upgrade, and recycle [108].

Additionally, this business model employs the product life extension strategy by pressuring service providers to pick or manufacture products that last longer. Since a product with a longer lifetime means more revenue for the service company. Aside from that, service companies have the incentive to create partnerships with multiple other companies invested in product and materials circularity, hence, creating a circular economy supply chain as illustrated in figure 3.3.

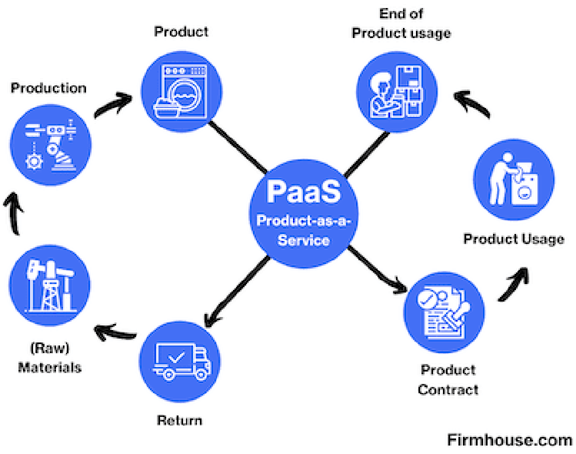


Figure 3.3: Product-as-a-Service (PaaS) and The Circular Economy [94]

PaaS Business Model applied in the PV market

In the context of solar PV systems, the product-as-a-service business model can be applied by leasing the PV system to the customers in return for a subscription fee. There are two primary types of PaaS models. The first one, often referred to as leasing, is where consumers pay a monthly fee, granting them personal access to all the energy generated by the system [137]. The second option is a Power Purchase Agreement (PPA), where the consumer pays a set fee for each kWh produced by the system [137]. These types of business models will be discussed in more detail in the pricing scheme section later in the report.

As already mentioned, the PaaS business model within the PV market offers numerous advantages:

- **Economic** The PaaS model can lower energy costs for consumers by offering them cheaper solar energy compared to the market price of electricity.
- **Environmental** Since PV systems allow for clean energy generation [58]. In addition, the model enhances circularity as discussed in section 3.1.3, since companies leasing solar panels can continue to control the quality and sustainability of the panels themselves.
- **Social** The model allows the technology to be accessible for all users without the financial capabilities of purchasing a PV system [58].

Use Cases

Numerous individuals and businesses relied on the PaaS model to generate solar electricity, and their diverse experiences and feedback shed light on the multifaceted aspects of this approach.

For example, according to Schmidt-Costa et al. (2019), one of the most successful implementations of the PaaS model within the PV industry is the California Solar Initiative (CSI). The California Solar Initiative is a ten-year program launched in 2006 to extend the solar PV market in California. The target was to install 1750 MW of solar PV capacity including both purchase and product-as-a-service options. The study aimed at assessing the impact of the PaaS business model on the California Solar Initiative (CSI) program showed that the PaaS model significantly increased the adoption of PV systems in California, introducing an opportunity to adopt solar PV systems and fostering customer enthusiasm. Consequently, this business model showed the potential to support market expansion and financial incentive policies.

Another study conducted by Rai and Sigrin (2013) indicated that the leasing model has unlocked a previously untapped consumer group, particularly those with a tight budget, to adopt PV technology. The study also expects that product as a service for PV systems will become the dominant method of adoption, as PV spreads to lower-income households [95]. Moreover, multiple players in the solar leasing industry such as Phoenix Solar and Sunseap (Singapore) have successfully implemented PV leasing projects with various organizations and companies, therefore highlighting the potential of solar PV leasing in the future [111]. This was also highlighted by the company SunRun, where the company adopting the solar-as-a-service business model showed a 24% increase in its customer base between 2018 and 2019 [19].

In the Netherlands, numerous companies applied the PaaS model by offering solar PV renting and leasing services. The main players in the Dutch market are Solease, SolNet, Joulz, and Zelftstroom which will be discussed in more detail in section 3.3.2. In addition, the non-profit foundation Wocozon in cooperation with housing associations such as Woonin and others, allowed tenants living in social housing dwellings to rent solar panels for a fixed monthly subscription [147]. According to Wocozon, tenants were able to save between 200 and 500 euros per year on energy savings [146]. Additionally, according to BNG Bank, about 50 corporations are affiliated with Wocozon with a total of 300,000 social rental homes, from which 35,000 have solar systems installed on their roofs [13]. As a result, Wocozon is greatly contributing to making housing associations more sustainable and ensuring affordable energy costs for tenants.

Moreover, producers such as Solarge and Exasun encouraged the adoption of energy-as-a-service business models as a way to enhance the circularity of PV panels. This is done by preserving the responsibility of the companies which incentivizes them to extend the lifetime of their systems. In addition, at the end of the life of the panels, manufacturers can more easily collect back the materials and ensure the reuse or recycling of new solar panels [55].

On the other hand, many drawbacks and limitations were also recorded in multiple PaaS adoption cases. A study conducted by Palmer et al. (2012) indicated that this business model did not reveal significant success throughout history in the residential sector. Moreover, energy services companies can better benefit from economies of scale when dealing with large customers who install hundreds or thousands of times larger sized PV systems compared to residential customers [19].

These case studies contribute to the body of knowledge by providing real-life experience on the application of PaaS models in the PV industry. Also, they offer recommendations and feedback that can be applied to this study to avoid previous mistakes and obstacles.

3.1.4. Portable PVs

In this section, portable PV technology is introduced in the solar energy market as a solution to be used in combination with the PaaS model. In addition, the section indicates how this technology can be used to address the barriers discussed in chapter 1.

Technology

Portable PVs were introduced by numerous solar manufacturers and energy companies. These devices help customers living in apartments and rental properties to install this technology on their balconies and be able to move it easily in case they move to another property. A portable PV system usually consists of one to a few solar modules with an output ranging from 300 to 800 Wp, a micro-inverter, and a mounting frame. The system is connected to the house grid using standard Schuko plugs as shown in figure 3.4 [57] [96]. Devices connected to the power grid of the household can directly benefit from the generated solar electricity. In addition, the price of portable PV systems varies from around 600 to 1,200 euros depending on the number and capacity of the panels and the manufacturer [78].

Figure 3.4: Portable PV Solar System [57]

How can portable PV systems overcome challenges?

Portable PV systems offer multiple benefits enabling customers to address multiple previously faced challenges:

- **Space-Efficient** Portable PVs allow for solar electricity generation even when roof space is limited. It therefore allows efficient use of space, especially in urban apartments where roofs and outdoor spaces are limited.
- **Ease of Installation** One main benefit of these systems is their ability to be easily installed without the need for specialized technicians. The system's mounting structure is designed to hang on the balcony railing and sheds without the need for complex modifications.
- **Accessibility** Since these systems are easy to install and remove, renters can comfortably install the system during the contract period and remove it at the end of the contract. Hence making solar PV systems accessible to a broader demographic.
- **Reduced Energy Bills** Even though portable PV systems have a relatively low capacity and electricity yield, they can supply enough electricity to power the quiescent components of the home. Research showed that a portable PV system can reduce the electricity bill by approximately 100 to 200 euros annually, making these systems pay for themselves in 5 to 7 years [151].
- **Environmentally Friendly** The system also helps in generating clean and renewable electricity. Hence, participating in reducing CO2 and greenhouse gas emissions.

Even though portable PV systems can address multiple challenges, they also have some drawbacks that are worth mentioning. In fact, a portable solar PV system is expected to generate between 500 and 1200 kWh per year depending on the inclination of the module [15] [16]. According to the Centraal Bureau voor de Statistiek (2016), the electricity consumption of apartments in the Netherlands is approximately 2,070 kWh per year. This means that the maximum power generated by a portable solar energy system is not enough to cover the consumption of an average apartment in the Netherlands. Moreover, portable solar PV systems are usually placed on balconies and sheds meaning that they are more exposed to shading caused by the surrounding environment compared to traditional rooftop solar systems. This can further decrease the electricity generated by the PV system and hence affect the profits of the system for end-users.

3.1.5. Main takeaways

This literature review identified a significant barrier to the adoption of PV systems in residential settings, particularly for tenants. It was observed that a large part of residential properties face obstacles in installing PV systems mainly due to restrictive rental contracts and limited space availability. Looking into the current strategies and PV solutions available to tenants, it was found that only a limited number of sustainable solutions are offered. These barriers were observed to slow the pace of residential PV growth and adoption in the coming years, thereby affecting the national energy goals set by the country.

Next, the adoption of the PaaS business model in this context was examined, and multiple cases have explored the adoption of the PaaS model in the PV industry in general. However, there exists only a sparse number of studies focusing specifically on the application of this model to portable balcony PV systems. This research gap reduced the volume of data collecting stakeholders' needs and preferences concerning balcony PV system leasing. In addition, with the absence of companies offering PaaS balcony PV business models, limited assessment of the financial and environmental viability of these models exists.

However, from the literature, it was observed that the PaaS business model potentially offers circular benefits by extending the lifetime of leased products. Along the same lines, portable PV systems were identified as a viable alternative for overcoming the challenges of accessing PV systems for tenants and people living in apartments.

Building upon this, this project aims to explore the implementation of the PaaS models for balcony PVs in the Netherlands, studying how the PaaS business models can expand the PV market and enhance the circularity of PV.

3.2. Stakeholder analysis

3.2.1. Identifying key stakeholders

In this section, the involved stakeholders in the portable PV PaaS industry are identified. The key players, their roles, and the impact they have on the growth of the portable PaaS business model are explored to ensure that their needs and interests are considered. Next, these stakeholders are categorized according to their primary, secondary, or tertiary roles to assess their influence on the project. By assessing their influence, stakeholders can be managed based on their interest and impact on the project.

Key stakeholders list

1. **Manufacturers and Suppliers**

   Manufacturers are companies responsible for the design, manufacturing, and quality assurance of PV panels and other PV system components such as inverters or even mounting structures. They are usually large-scale industries that are mainly interested in maximizing their sales. An example of solar panel manufacturers are Jinko Solar, JA Solar, Aiko Solar, and LONGi [25].

   It is worth noting that the manufacturers and PaaS providers can be combined into one company. This has important implications in affecting the durability of the products offered, as manufacturers have an incentive to design more durable products with a higher lifetime to ensure higher long-term profits. This might not be the case if the manufacturers and PaaS providers are separate.

2. **PaaS Providers**

   PaaS providers own balcony PV systems and lease them out to end-users for a subscription fee. Their main interest is to maximize their profit by selling the electricity produced by their balcony PV systems. Examples of PaaS providers are Zelfstroom and Solease [148] [120]. These providers can also be affiliated with larger energy companies such as Eneco Groep, Shell, and bp (Netherlands) [47]. These service providers can be responsible for delivering balcony PV systems to the customer's location, ensuring an adequate installation, and performing regular check-ups and maintenance. These tasks can be assigned to a third party or can be managed by relying on in-house installation and maintenance services. By providing these services themselves, companies can reduce their costs compared to partnering with separate service companies. In this project, the company is assumed to provide in-house installation, maintenance, and shipping services.

3. **End-users**

   End-users are at the core of the balcony PV PaaS model. This group consists mainly of residents of rental properties and apartments who are interested in covering their energy needs cost-effectively and sustainably. They play an important role in shaping the market according to their needs and preferences. They assess the attractiveness of the proposed PaaS model depending on multiple factors such as price, reliability, durability, flexibility, and aesthetics. Their assessment of the model significantly affects the adoption rate of the offered product or business model. In addition, their feedback can offer valuable data for service providers and manufacturers to improve the product and make it suitable for the customers' needs.

4. **Rental Property Owners**

   Property owners are also central because they own the property and must provide permission for the installation of balcony PV systems on it. These actors are mainly interested in increasing the value of their property and enhancing its sustainability features.

5. **Investors and Financial Institutions**

   Investors and financial institutions provide the required financial support for the implementation of the PaaS business model. Consequently, they are interested in achieving favorable returns on their investment. Examples of investors are banks, the private sector, and institutional investors.

6. **Policy Makers and Regulatory Bodies**

   These stakeholders play a central role in setting and enforcing policies and regulations that directly affect the implementation and success of PaaS business models. They are primarily interested in reaching their national energy targets. Hence, they set regulations and offer subsidies to support the adoption of renewables and ensure PV systems are compliant with safety standards.

7. **Electricity Providers**

   These parties are responsible for generating and supplying energy in the Netherlands. They offer a wide range of services from traditional and renewable supply of electricity. Examples of these companies in the Dutch electricity market are Eneco, Vattenfall, and Essent.

8. **Grid Operators**

   These actors manage the grid to which the portable PV systems are connected. Their role is to facilitate the integration of solar PV into the grid, manage energy flow, and ensure the compliance of PV systems with safety and efficiency standards. In the Netherlands, the grid operator is TenneT and the distribution system operators consist of companies like Stedin, Liander, Enexis [123] [135].

9. **Research Institutions**

   Research institutions are essential in improving and innovating portable PV systems to suit the requirements of the previously mentioned stakeholders. Their interest is to design environment-friendly, cost-effective, and efficient PV technologies. Examples of these institutions are the Energy Research Centre of the Netherlands (ECN) which is a part of TNO, and universities like TU Delft, and TU Eindhoven (TU/e) [82].

10. **Environmental Advocacy Groups**

    These stakeholders are interested and responsible for raising public awareness about sustainability and the environment, hence encouraging consumers to adopt renewable and sustainable energy solutions. In addition, they pressure policymakers on the introduction of supportive regulations and incentives to foster the integration of the discussed model. Examples of advocacy groups in the Netherlands are Holland Solar, Natuur & Milieu and Wise Nederland [114] [77] [79].

11. **Insurance Companies**

    Insurance companies offer insurance and guarantees to energy service companies and end-users against potential risks that might arise throughout the subscription period of the PaaS model. Consequently, they help end-users gain trust in adopting the PaaS portable PV business model and ensure financial security for the PaaS providers.

12. **Housing Associations**

    Housing associations are responsible for providing accommodation and quality of life for older people and people with disabilities [48]. In fact, according to the Dutch Government, 75% of rented homes are owned by housing associations. Hence, integrating BPV systems in their houses can accelerate the adoption of balcony PV systems [48].

An important observation is that PaaS providers can take different roles and statuses. For example, they can be responsible for the manufacturing and leasing functions and offer installation and maintenance services without partnering with third-party companies. Other cases involve the PaaS providers partnering with manufacturers and outsourcing their installation services. As multiple approaches exist, it is important to understand the benefits and drawbacks of each of them and have a clear overview of the company's portfolio to ensure a more accurate assessment of the business model studied.

Stakeholders Categorization

The previously mentioned stakeholders differ in terms of their significance and should be classified into distinct categories. In this section, stakeholders are categorized as primary, secondary, and tertiary.

1. Primary stakeholders include individuals and groups directly impacted by the project. Examples of primary stakeholders in this study are:
   - PaaS Providers
   - End-users
2. Secondary stakeholders include individuals or groups with the ability and interest to influence the project's outcome such as:
   - Property Owners
   - Government and Regulatory Bodies
   - Manufacturers and Suppliers
   - Investors and Financial Investors
3. Tertiary stakeholders consist of individuals or groups who may not have direct involvement in the project or policy but can offer valuable perspectives that contribute to the study. These stakeholders in our case are:
   - Insurance Companies
   - Housing Associations
   - Grid Operators
   - Research Institutions
   - Environmental Advocacy Groups
   - Electricity Providers

After identifying the main stakeholders involved in this study, a map is created to show the connections between them in section 3.2.2.

3.2.2. Stakeholder Mapping

In this section, the different types of interactions between stakeholders are indicated. These interactions include financial transactions, goods and services, information exchange, and permissions and subsidies. Analyzing these connections is crucial as they help clarify the roles and interactions of the stakeholders involved.

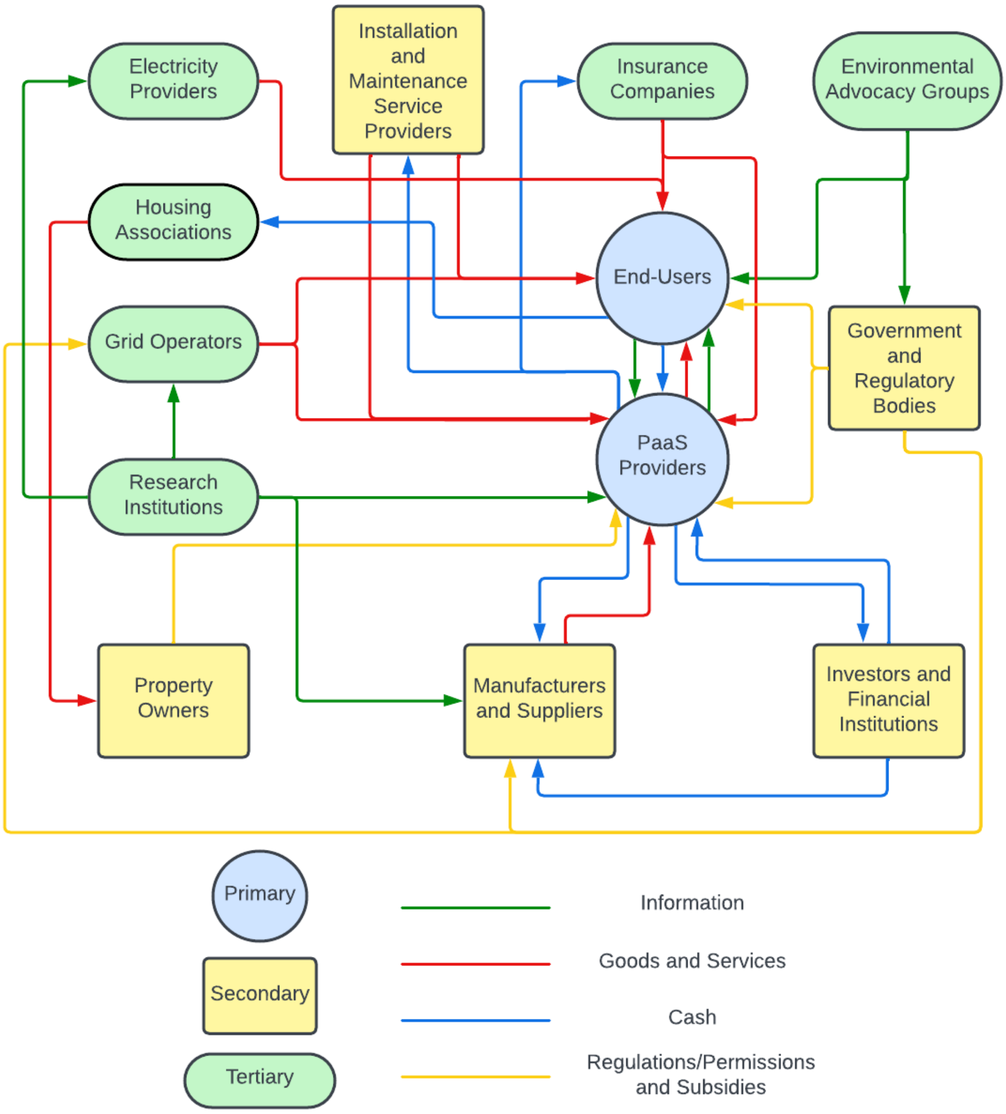


Figure 3.5: Stakeholder Mind Map

3.2.3. Financial Transactions

Financial transactions between the different stakeholders are indicated by blue arrows in Figure 3.5. Firstly, investors and financial institutions provide funds and support to PaaS providers, manufacturers, and suppliers. In return, PaaS providers pay the manufacturers for the supply of PV modules and other components. Additionally, PaaS providers pay maintenance and installation service providers and insurance companies for the services they provide. Once all systems are installed, PaaS providers start earning money from end-user subscriptions. Finally, investors receive payments from PaaS providers in return for their investments.

Provision of Goods and Services

The supply of goods and services between the different stakeholders is indicated by red arrows in Figure 3.5. The PaaS providers offer BPV systems to end-users under the PaaS business model. On the other hand, insurance companies provide BPV system insurance for end-users in case of any malfunctions or unforeseen events. Moreover, insurance companies offer compensation to the landlord in case of any damage to the apartment or building. In addition, installation and maintenance service providers take care of installing and regularly maintaining BPV systems. Manufacturers and suppliers supply the required BPV components for the PaaS providers. Finally, grid operators work with the PaaS providers and end-users to ensure the BPV system is connected to the utility grid and is compliant with the safety and efficiency standards.

Information Exchange

Information exchange between the different stakeholders is indicated by green arrows in Figure 3.5. Research institutions share information with manufacturers and suppliers about the latest developments in BPV systems. In addition, they suggest improvements for PaaS providers to incorporate in their PaaS business models. Aside from that, environmental advocacy groups work on conveying environmental public awareness to end-users and pressure the government to introduce more renewable energy policies and regulations. Finally, PaaS providers offer education services for end-users about the benefits of BPV systems. In return, end-users give feedback to PaaS providers on their experience with BPV PaaS business models for future improvements.

Regulations, Permissions, and Subsidies

Regulations, permissions, and subsidies offered by the government and landlords are indicated by yellow arrows in Figure 3.5. For the PaaS providers and end-users to install BPV systems on their apartments, they should be granted the permission of the rental property owners. In addition, the government and regulatory bodies provide regulations and policies that manufacturers, suppliers, PaaS providers, and end-users must comply with. Moreover, the government sometimes offers subsidies for end-users wishing to adopt residential solar technologies.

3.2.4. Stakeholder interests, needs and impact

After analyzing the interests, needs, and impacts of the involved stakeholders on the business model, it is possible to classify them by identifying whom stakeholders to focus on, allowing each stakeholder to be effectively managed and categorized according to his position. A suitable tool for this classification is the power-interest matrix, where the degree of power and interest are indicated by the y-axis and x-axis, respectively. As shown by Figure 3.6, the matrix is separated into four main quadrants.

- **Low Power/Low Interest**

  The green quadrant, for example, indicates low power and low interest. Stakeholders in this category are not very engaged and require minimal attention compared to other actors in the market. In this section lie insurance companies, and electricity providers as their participation is of moderate power and they are not at the center of the residential solar market.

- **High Power/Low Interest**

  The yellow-colored quadrant indicates stakeholders with a significant influence but limited interest in the project. Stakeholders falling in this section should be kept satisfied without overwhelming them with the project's details. In this quadrant falls grid operators which are responsible for maintaining a reliable and stable supply of electricity and possess the power to allow for solar PV integration with the grid. However, they are moderately interested in the success of the project.

- **Low Power/High Interest**

  The blue quadrant represents stakeholders who are highly interested in the studied business model, however, they individually have limited influence on it. These stakeholders should be kept informed and their feedback and assessment should be collected to shape the business model accordingly. Examples of stakeholders in this category are end-users and property owners, as they are interested in the advantages of the solution but have low contribution and influence individually. Research institutions are also part of this category since they are crucial in designing innovative products and business models to constantly improve solar energy products and models. In addition, manufacturers and suppliers help manufacture innovative portable PV systems and are interested in the success of the model since this would mean more profit and a larger market share in the industry. Lastly, environmental advocacy groups are also highly interested in boosting the adoption of solar systems since this would lower greenhouse gas emissions and achieve higher sustainability.

- **High Power/High Interest**

  Finally, the red quadrant represents high-power and interest stakeholders essential for the project's success. The involvement of these stakeholders is crucial and they should be managed closely by regularly communicating and strategically engaging with them. The companies providing the portable PV PaaS model are part of this quadrant since they are responsible for setting the business model features and specifications and choosing a suitable portable PV system. Consequently, any inconvenience in their model could negatively impact the reputation of the company and hence affect the demand for the service. Moreover, the governmental authorities play a main role in setting the regulatory frameworks and offering subsidies which can either hinder or boost the adoption of the portable PV systems. In addition, financial investors are also crucial actors in this project, as they own the financial means and their willingness to invest in the project directly influences its outcome.

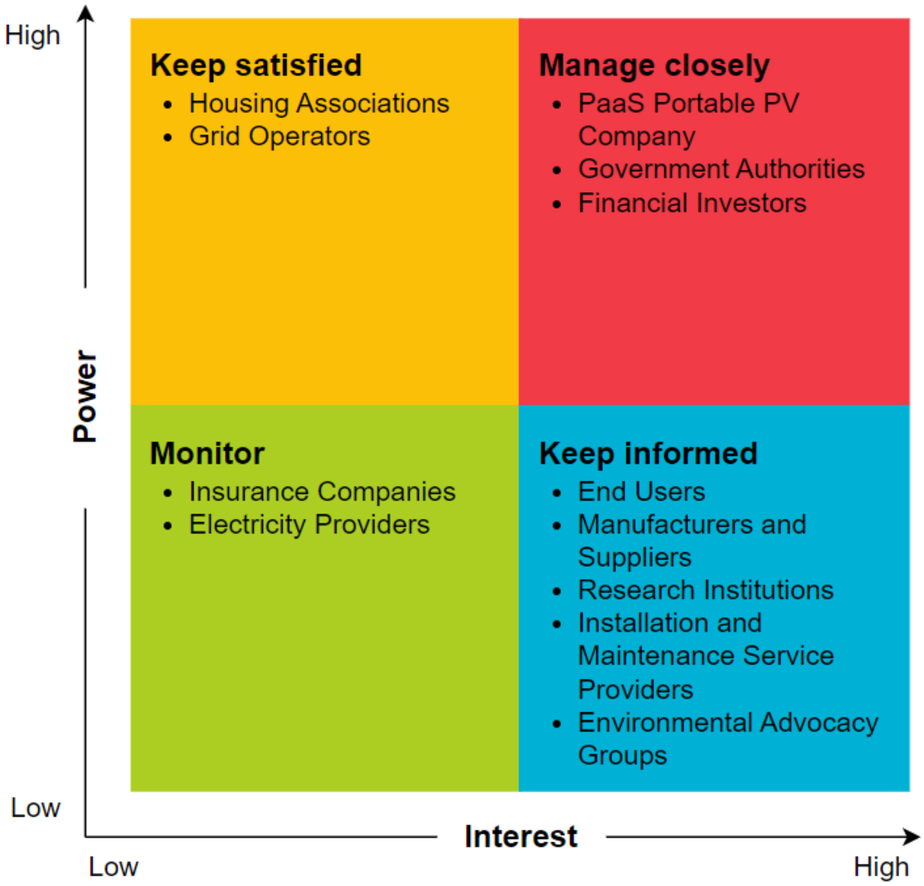


Figure 3.6: Power Interest Matrix

3.3. Market analysis

In this section, the state of the residential solar sector is evaluated to gain an understanding of its current size, in addition, to forecasts of its growth. After identifying the state of the market, a competitive analysis is conducted to highlight the strengths and weaknesses of key competitors in the market. Next, the market is segmented and the consumer's behavior is analyzed to gain insights about the preferences and needs of these actors. Finally, the economic, technological trends, social, and regulatory influences identified outline the market challenges and opportunities that affect the market.

3.3.1. State of the industry

This study primarily focuses on the utilization of portable PV systems under the PaaS business model. Specifically, the consumers of interest are customers in the residential sector who are interested in subscribing to this service. Therefore, this market analysis zooms in on the residential solar PV market, a segment within the broader solar PV industry.

First, it is crucial to evaluate the market's size and growth trends. This analysis will help determine whether the market is large enough and experiencing substantial growth. Hence, knowing whether there is a viable opportunity for entry.

Market Size and Growth

Over the past decade, the accumulated installed residential solar PV capacity in the Netherlands has increased from 0.182 GW in 2012 to 4.95 GW in 2021, indicating a substantial growth in the PV residential market as shown in figure 3.7 [59]. In addition, the additional installed residential solar capacity in 2021 was approximately 1.3 GW compared to 1.1 GW in 2020, indicating an 18% growth in yearly installed capacity as presented by figure 3.12. This shows that the residential installed capacity increased significantly in the past decade and was continuously growing till 2021.

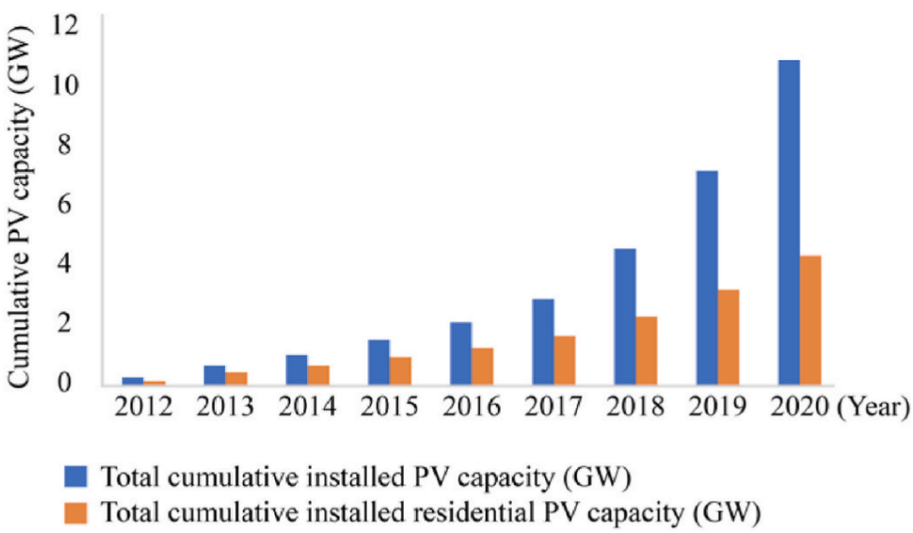


Figure 3.7: Growth in solar PV capacity in the Netherlands [59]

This growing trend is also supported by Figure 3.8 which displays an increase in the annual installed PV capacity from 450 MW in the first half of 2019 to 650 MW in the second half of 2021, indicating a growing trend in the residential PV market between 2019 and 2021 [7].

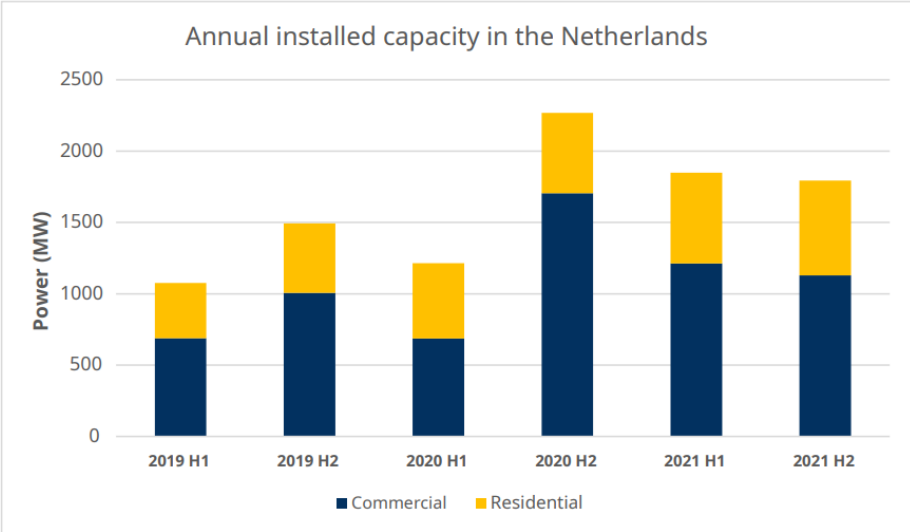


Figure 3.8: Annual Residential and Commercial Installed Capacity in the Netherlands [7]

In addition, Figure 3.9 published by the International Energy Agency (2020) shows the additional annual residential solar PV from 2018 to 2020 and two projection scenarios for the years 2020 to 2025. One scenario represents the main case which is the expected average annual additions under current policies and market conditions. The second scenario is the accelerated one which assumes more aggressive policies leading to higher annual additions. This chart expected a 0.6 GW additional residential capacity installation under the main case scenario in 2020. In contrast, statistics from the Netbeheer Nederland report issued by the Dutch Association of Power Networks Operators indicated that the Netherlands was able to install around 2 GW of additional residential PV capacity in 2022. Hence, comparing information from the two sources shows an increase of approximately three times between the actual additional installed capacity and the expected capacity by the International Energy Agency [15]. This indicates that the Netherlands was able to significantly surpass its forecasts in the residential PV markets, therefore reflecting the rapid growth of the market.

Furthermore, the Dutch utility company Liander stated that more than 153,422 new residential solar PV systems offering 699 MW capacity were installed in 2022 which is 25% more than 2021 [15]. In addition, as indicated by Figure 3.12, the capacity of additional solar PV increased from 1.3 GW in 2022 to 1.8 GW in 2023 marking an outstanding year-on-year growth of 37% and a 10% increase in the residential market share caused by the strong increase in electricity price levels [34].

It is also important to mention that in 2022 the residential solar PV market segment achieved a 46% share of the total solar market making it the biggest solar market segment in the Netherlands [38].

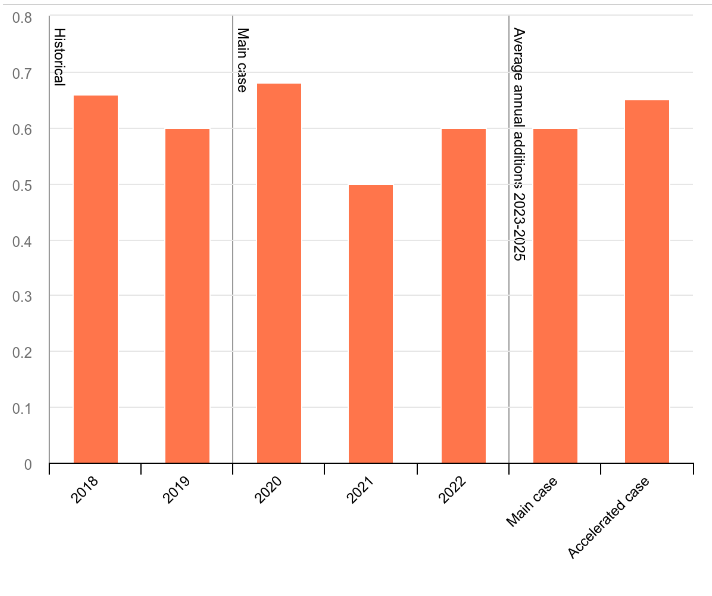


Figure 3.9: Netherlands solar PV capacity additions, 2018-2022 and average annual additions, 2023-2025 [53]

On the European level, Germany reserves the first place in terms of annually installed solar capacity in 2023 with a capacity of 14.1 GW, as shown in Figure 3.10, where 50% resulted from residential PV capacity. On the other hand, Spain, and Italy installed new residential capacities of 2.55 GW, and 3.16 GW respectively, in 2023. However, dividing these capacities by the total population of the country results in the Netherlands occupying the first place in terms of newly installed residential solar capacity per capita with a value of 101.7 W/capita, compared to Germany with a capacity of 84.3 W/capita and Italy and Spain with values of 53 W/capita. This reflects that the Netherlands was able to secure a favorable position within Europe in 2023 in the solar market and especially in the residential solar sector [37].

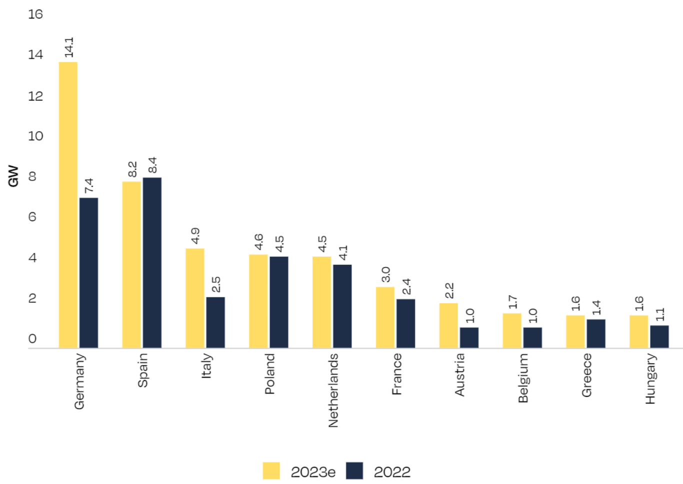


Figure 3.10: Top Ten European Solar Markets 2022-2023

Moreover, Figure 3.11 issued by the Netherlands Enterprise Agency (RVO) and other energy companies and agencies, forecasted the cumulative solar PV capacities from 2020 to 2030. The graph indicates a cumulative 13 GWp of solar PV capacity in 2030, equivalent to approximately three times the capacity of 2022. Hence, this emphasizes the fact that the residential PV market is expanding, leaving sufficient space for further advancements and investment opportunities.

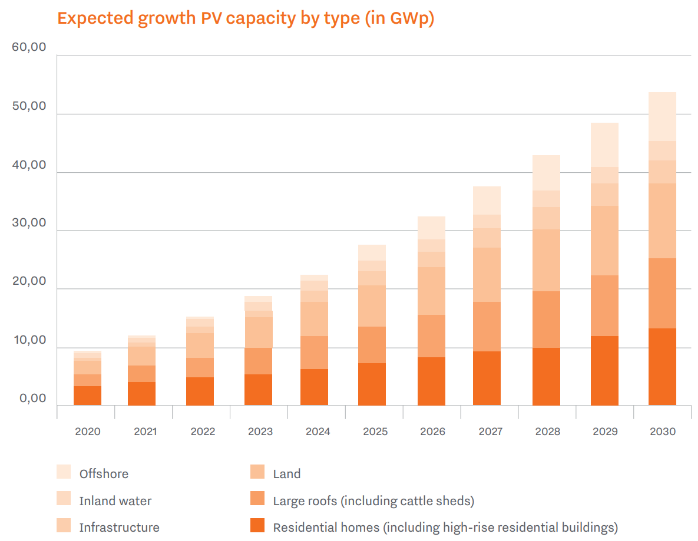


Figure 3.11: Netherlands expected cumulative PV capacity by type (in GWp) 2020-2030 [105]

On the other hand, forecasts projected by the Dutch New Energy Research indicated that an 18% decline in the capacity of newly installed residential PV systems will take place in 2025 compared to 2022 [51]. This decline was also supported by Figure 3.12 where the expected additional solar PV capacity highlighted by the yellow bar shows a decline starting in 2022 and stabilizes at around 1.4 GW per year in 2025 and 2026 [34].

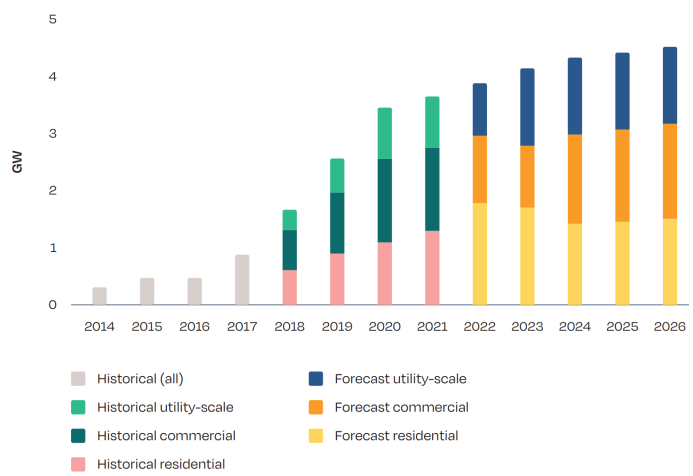


Figure 3.12: Netherlands expected solar PV capacity additions 2022-2026 by type (in GWp)

In addition, Daan Jansen, a lead researcher at Dutch New Energy Research, expects a shrinkage in the residential PV market in the country because more buildings will already be equipped with PV systems. Jasen also mentioned that it is not realistic for the residential market to continue growing at the rate observed in 2023 since under this growth all the households in the Netherlands will have PV systems installed on their roofs in a couple of years. Additionally, he added that the only way to achieve the 2 GW peak observed in 2022 is by increasing the average electricity grid capacity [45].

Furthermore, a reduction in residential PV capacity is expected in the coming years after the new government in the Netherlands agreed on abruptly phasing out the net metering scheme in 2027 [66].

3.3.2. Competitive Landscape

In this section, the competitive landscape of the Dutch residential solar market is analyzed by identifying the key players and evaluating their respective strategies, strengths, and weaknesses. This provides an understanding of the products available in the market and spots threats and opportunities caused by these competitors.

Key Players

The key players in the Dutch residential solar market can be segmented into different categories:

1. **Portable Solar PV Providers**

   These companies are mainly responsible for designing, installing, and maintaining portable solar PV systems that can be easily installed and used in various settings, such as balconies, sheds, and other outdoor activities.

   - **Balkon Solar**
     Balkon Solar is a Dutch solar company offering numerous solar balcony PV packages with regular socket plugs as shown in Figure 3.13 [11]. These systems allow for easy and safe installation by the customers themselves while adapting to the countries' regulations.

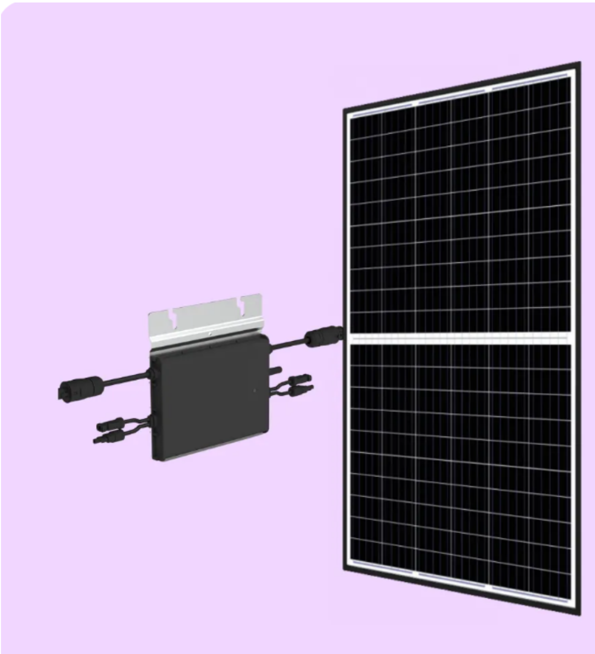


Figure 3.13: Balkon Solar Portable PV Product [12]

   - **We Do Solar**
     We Do Solar is a German-based startup that has developed an innovative kit consisting of eight balcony solar modules intended for use by apartment dwellers, as shown in Figure 3.14 [143]. Due to the rising of electricity prices in Europe after the Russian invasion, We Do Solar witnessed a surge in demand leading to the rapid growth of the company. It reached a customer base of 3,000 customers in the first month surpassing twelve times its expectations [41]. In the future, the company is planning on adding renting features for its products to make it accessible for renters who don't wanna commit to buying portable PVs.

Figure 3.14: We Do Solar Portable PV Product [144]

It is important to mention that solar PV systems intended for balconies, sheds, and other spaces can be bought from any wholesale PV panel provider. With the help of a professional technician, these panels can be combined with a microinverter and a suitable mounting structure allowing them to be directly plugged into regular sockets and hence be used as portable PV systems.

2. **Solar Panel Leasing Firms / Energy as a Service**

   This section presents the companies offering solar panels or systems for renting or leasing.

   - **Solease**
     Solease is a Dutch solar rental startup based in Utrecht that started offering solar panel renting services in 2011 [31]. Hence, the customers rent the PV panels in return for monthly subscriptions that are lower than wholesale electricity prices [122]. The company takes care of purchasing, financing, monitoring, and repairing rented solar systems. According to Solease, their systems allow for a 10 to 20% reduction in energy costs, reductions in CO2 emissions, and flexible contracts allowing customers to transfer the systems to their new homes after relocation [31].

   - **Zelfstroom B.V**
     Zelfstroom is a sustainable solar energy company that originated in the Netherlands in 2014 [148]. Its services revolve around assembling, installing, repairing, and leasing various types of solar panels for residential and commercial end-users. It is currently the market leader in lease and solar panels renting for residential and commercial buildings in the Netherlands. Zelfstroom offers solar panel renting options for 10 or 15 years in return for a fixed monthly subscription. According to Zelfstroom, consumers can save up to 0.15 €/kWh if they subscribe to their services instead of buying electricity at wholesale prices [148]. At the end of the contract, the consumers are allowed to buy the solar system for an affordable price. The company offers other services such as financial consultations and rooftop checks to inform their end-users about additional customized cost savings and permits needed for installing their PV systems.

After identifying the key players in the Dutch residential solar market, their target customers, strengths, and weaknesses are assessed to gain a better understanding of their position in the market in section 3.3.2

Competitors' Strengths and Weaknesses

In this section, the target customers, strengths, and weaknesses of competitors in the Dutch residential market are assessed. This gives a clearer view of the strategies employed by these key players and how their presence in the market acts as a challenge or opportunity for the success of the studied business model.

	Portable PV System Providers	**For Solar Leasing Firms**
Target Customer Group	• Tenants and apartment residents with limited space availability	• Homeowners and long-term contract tenants interested in adopting solar PV systems without upfront investments
Strengths	• Mobility • Ease of Installation • Low-Cost Products • Suitable for Backup Power	• No Upfront Investment • Broad Customer Base • Enhanced PV Circularity • Long-term Customer Relationships
Weaknesses	• Low Energy Yield • Limited Customer Segment	• Long-term Contracts Discourage Customers • Higher Lifetime Costs to End-Users • Logistical Complexity [a] • Deferred Revenue Collection [b] [a]This represents the challenge of managing the distribution, maintenance, and retrieval of portable PV systems under the PaaS business model [b]This represents the challenge of waiting for subscription payments over time, as opposed to immediate cash flow generated from direct sales.

Table 3.1: Target Customers, Strengths, and Weaknesses of Key Competitors in the Dutch Residential Solar PV Market

According to the findings of this section, the market competition in the Dutch residential solar PV market is low because of the absence of companies offering portable PV under the PaaS business model. The main players in the market offer either portable PV systems or rental services for rooftop solar PV systems, meaning that a combination of the two strategies is not present. Even though We Do Solar is working on developing rental services for balcony PVs, the idea has not yet been applied and no official launch of the service is indicated. Hence, the absence of competitor companies with the same business model under study constitutes a significant opportunity to enter the market and target segmented customers.

3.3.3. Consumer Analysis

To thoroughly analyze consumer behavior in this market, market segmentation was conducted where the target segments were identified and categorized based on their size and characteristics. Next, the behavior of potential consumers was analyzed by focusing on their preferences and concerns. Understanding this behavior helps design the business model to meet their needs, hence boosting its adoption rate.

This analysis relied on quantitative data obtained from a survey of 46 participants that included a variety of demographic, geographic, behavioral, and psychographic questions. Additionally, qualitative data was gathered through interviews with six tenants to provide deeper insights into customer behavior.

Target Segment

Segmenting the market is a crucial step for designing a product or business model since it helps identify the main customer segments targeted along their size and characteristics. While surveys are effective tools for this type of analysis, only 46 individuals participated in the survey employed in this study, which was not found to be fully representative of the market. Consequently, no definitive identification of target customers was possible. However, insights retrieved from the results suggest that the business model is most appealing to renters with short-term contracts and those living in limited-space properties like studios, flats, and apartments.

Moreover, according to the Centraal Bureau voor de Statistiek (2020), four out of ten Dutch homes are rental properties [126]. In addition, around 53% of these properties are apartments, hence forming the largest share of rental properties in the country [67]. However, less than 1% of these rental apartments have installed solar PV systems, placing them at the bottom of the list compared to other types of dwellings [125]. This is mainly because all these apartments face space constraints as the roof is shared and cannot be used for personal benefits and no temporary solar solutions are offered by the market to target the needs of these renters.

Consumer Behavior

To gain deeper insights into customer preferences and needs, multiple questions were posed in the survey followed by open questions asked in the interviews with the potential customers as outlined in appendix A. These questions take into consideration specific features of portable PV systems (PPVs), the PaaS business model, and other sustainability and aesthetics aspects. The data collected by this survey will help tailor the studied business model to better align with the customers' expectations and needs.

Starting with Q12 in the survey, which aims to identify the primary motivations driving end-users to adopt PV systems. This question provides valuable data about the main factors and aspects that customers look for when considering PV installation. According to the survey's results represented by Figure 3.15, approximately half of the participants (47%) of respondents to the survey and all the interviewees expressed interest in installing solar PV systems primarily to reduce their electricity bills. On the other hand, environmental benefits were mentioned as a primary driver for 32% of participants in the survey, indicating a strong environmental awareness among some participants. These findings give insights into developing a business model focused on cost savings.

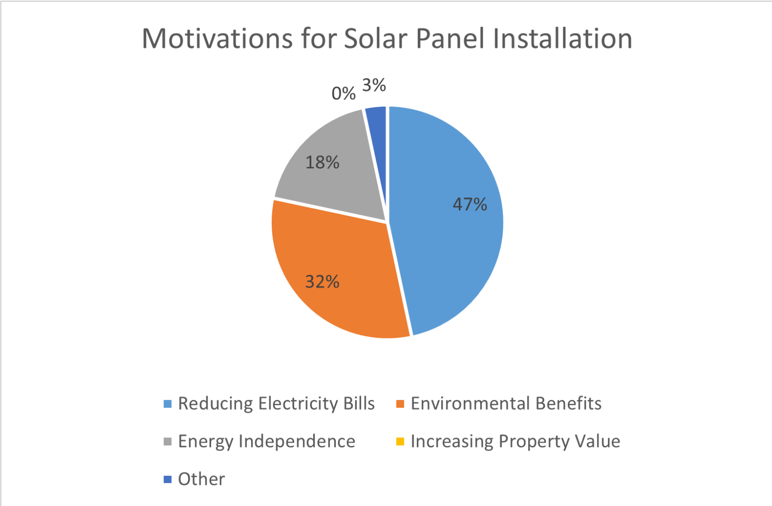


Figure 3.15: Motivational Factors Influencing Solar Panel Adoption Among Survey Participants

Following a brief introduction of portable solar PV systems, survey and interview participants were asked to specify their view on the appealing features of PPVs. It is worth mentioning that 6 out of 8 interviewees lacked information about portable PV systems and the ability to install them on balconies and sheds, meaning that more effort should be focused on educating end-users on the presence and benefits of these systems. According to the results of the survey, most of the participants selected the ease of installation, and cost-effectiveness of the system to be the most attractive features of these systems with respective percentages of 34 and 31%, as observed in the pie chart in Figure 3.16. This indicates that affordability and reduced technical complexities are key priorities that should be prioritized in the business model. In addition, 22% of participants are interested in PPVs for their compact size which helps them fit in limited spaces and store or move easily. Aesthetic considerations are less critical for consumers when looking at the features of the PPVs. Although 57% of the participants indicated a neutral view on the aesthetic effects of PPVs interview participants mentioned that aesthetics play a more crucial role, as will be discussed later in the barriers and concerns section.

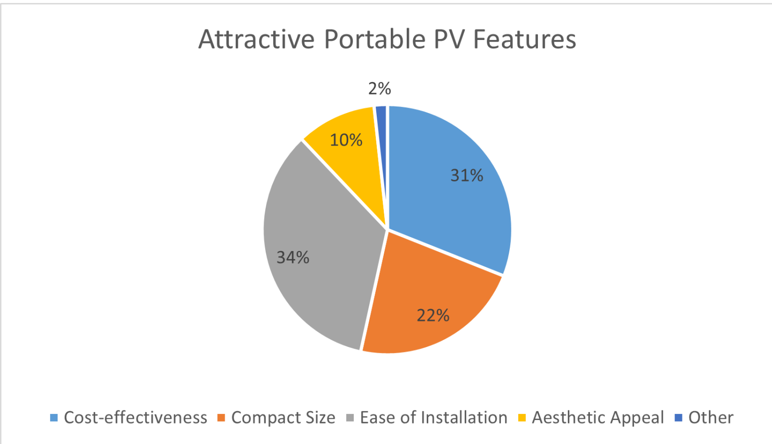


Figure 3.16: Preferences in Portable PV Features among Survey Participants

When presented with a description of the PaaS business model, survey participants indicated the absence or low upfront and investment costs as the primary attractive feature of the PaaS business model with about 37% of the participants as shown in Figure 3.17. This underscores a strong market opportunity for the model to minimize initial investment barriers for end-users. Then, the second most attractive feature was inclusive maintenance with 26% for both, hence, pointing towards a need for hassle-free solar PV solutions. This observation also holds for the majority of interviewees who mentioned that no initial costs, temporary and flexible contracts, and inclusive regular maintenance were the main attractive features they look for in a leasing business model.

During the interview, Q15 and 16 were asked to gain a better understanding of the decision to lease a PV system in the case of a short-term contract period and all the renters participating in the interviews were positive for the idea with the only condition being that the product should possess easy installation, removal and transportation features. This further highlights the importance of designing a DIY product with easy assembly and mobility characteristics.

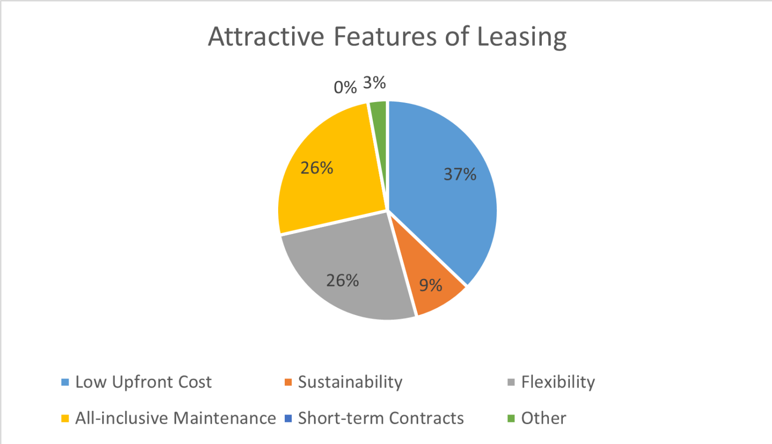


Figure 3.17: Preferences in Leasing Features among Survey Participants

Another key aspect of the PaaS business model that should be taken into consideration is the fact that PV panels installed for end-users are often secondhand, meaning that they have been previously used by other customers. This may reduce the attractiveness of the business model to customers as the efficiency of solar panels could be lower than newer ones. When asked about this concern in the survey, 51% of these participants indicated a positive view on the matter demonstrating their acceptance of the drawback. On the other hand, only a minority (14%) view the use of second-hand solar panels as a concern. The same results were observed throughout the interviews, however, some mentioned this to be dependent on the decrease in efficiency. For example, this would form a barrier for them when the panel's efficiency is substantially low and no reduction in the subscription fee was made. So even though most of the participants don't have an issue with leasing secondhand solar panels, strategies for quality assurance should be placed to address the concerns of the customers.

Among survey participants, 31% expressed their uncertainty about leasing portable PV systems, while 19% showed no interest. To better understand the concerns of these groups additional questions (Q13, Q26) were included in the survey, as detailed in appendix A. These questions helped gather more information on the main concerns and barriers realized by these groups to help address them in the business model.

In survey Q13, participants were asked to identify the main barriers preventing them from adopting a PV system, and 36% of respondents highlighted "Rental Property Restrictions" to be their main concern as observed in Figure 3.18. This highlights the importance of a business model with non-permanent and easy-to-install and remove features. In addition, 'High Initial Investment' was found to be the second most significant barrier for 24% of survey participants and the majority of the interviewees, reinforcing the need for an affordable entry into the solar PV market, such as a leasing model with low or no initial costs. Moreover, "Spatial constraints" at 18% indicate the necessity for space-efficient solar products. For most interviewees, aesthetic concerns were more important, where most of the participants mentioned that a PV module installed on a balcony or a shed somehow detracts from the design and beauty of a building. However, they also mentioned that this mainly depends on the location of the balcony and the shed (visible or hidden) and the type of PV technology employed. In addition, other participants in the interview indicated a concern for the safety of portable solar panels installed on balconies and their probability of falling off in the case of windy days in the country. Hence, choosing a sleek and aesthetic PV panel and a robust mounting structure can help address these concerns.

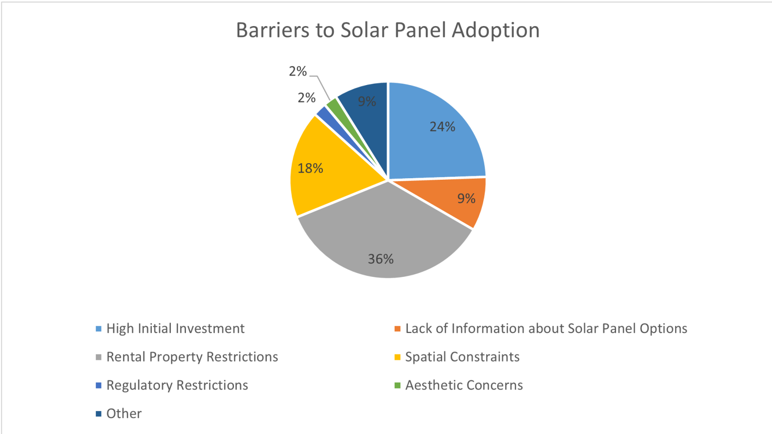


Figure 3.18: Barriers to Solar PV Adoption: Participant Perspectives

Cost considerations were serious concerns for the interview participants, who mentioned that all their previous leasing experiences were convenient and pleasant however, they couldn't keep up with the subscription for the service mainly because of long-term costs substantially exceeding the initial investment cost of the product. On the other hand, one of the participants mentioned that paying more costs in the long term is not a major issue in the case where the subscription is cheaper than the cost of conventional electricity supplied by the utility grid. Moreover, some participants mentioned that very low-cost savings can prevent them from adopting the business model as they don't feel the need to participate in a subscription model and contract without sufficient cost-saving potential. This further highlights the need to develop a pricing scheme that attracts end users to save on their energy bills.

Additional concerns were raised in response to survey Q33 regarding the ability to terminate the contract if the system was not found to be satisfactory. A common concern was also realized in surveys Q18, 27, 32, and 33 related to the future of net metering. In fact, more than 65% participants believe that the phase-out of this scheme can affect the adoption of solar energy systems in the residential sector. Additionally, some participants cautioned that this can result in a more expensive energy transition for the Netherlands, and is not advisable to rely on technologies adopting this scheme in the long term.

Main takeaways

To conclude, most potential end-users showed interest in installing solar PV systems primarily to reduce their electricity bills. However, a large part of them face challenges installing PV systems because of rental property restrictions, high initial investments, and space constraints. In addition, end-users mentioned their interest in subscribing to the PaaS business model mainly because it ensures low upfront costs, inclusive maintenance, and flexible contracts. When asked about the desired product specifications and features, the conditions were to provide an easy-to-install and remove process, an aesthetic product, and the availability of numerous customization options. Moreover, when asked about the idea of integrating PV cells into privacy screens, multiple end-users found it interesting as they indicated their value to privacy on their balcony. Some of the participants also mentioned their concern about leasing second-hand panels if they are not being compensated for the losses, indicating the need to ensure compensation and insurance guarantees in the pricing scheme.

3.3.4. External Influences

To understand the threats and opportunities present in the residential PV market, the external influences affecting the dynamics of the market were identified in this section. These external influences cover regulatory, economic, social, and technological factors.

Regulatory and Policy Environment

In this section, the current legislation, regulations, subsidies, and incentives employed by the government within the residential solar sector are explored, along with their impact on the Dutch residential solar sector. Looking into these regulations allows us to understand the threats or opportunities that these regulations impose on the studied market.

Regulations and Policies

The main regulations and policies currently employed by the Dutch Government consist of the following:

1. **Netting Arrangement** The Netting Scheme applies to consumers who are considered small-scale electricity contributors to the grid. This program is utilized by consumers who generate their electricity using solar panels [99]. This scheme allows consumers to sell their excess energy generated by their solar panels to the grid [116]. However, it is important to note that this scheme is going to be phased out in 2027, which could significantly affect the adoption of solar PV systems in the future.

2. **Renewable Energy during Major Renovation** This law established in 2022 obliges homes and buildings undergoing major renovations to include a minimum capacity of renewable energy technologies such as solar panels or heat pumps [99].

3. **Zero VAT rate** The VAT rate for the installation of solar panels on or next to homes and buildings was set to zero, hence mitigating the need for VAT refunds and exemptions [99] [106].

4. **OPEN Foundation Waste Management** This policy obliges producers and importers of solar panels within the European Union to gather and process discarded panels after their end of life. This law considers numerous types of electrical appliances. In addition, as of the year 2021, all solar panel manufacturers and importers must join the OPEN Foundation (Organization of Producer Responsibility for E-waste Netherlands) [99]. OPEN Foundation aims to collect and recycle all e-waste appliances in the Netherlands [130]. In addition, it is legally required to pay a waste management contribution fee which is included in the cost of solar panels and OPEN Foundation ensures this contribution is paid, hence creating transparency in the market [99].

5. **Balcony PV Permits**

   According to the VDE Association for Electrical, Electronic & Information Technologies assigned an 800W capacity limit for balcony PV systems at the European level [140]. Additionally, experts Michel Chatelin and Joris van de Bunt stated in an article from Solar Magazine that no general ban exists on placing solar panels on balconies and sheds in the Netherlands. However, before installing, the tenant or individual willing to buy portable PVs should investigate the rental contract regulations of the Owners' Association (VvE) [60] [12]. The VvE is the association responsible for the care of the property and serves the owners' communal interests with rules that are bound by Dutch rules and regulations. The VvE stated that installing items that are visible to the outside are considered common property and therefore require their permission [60]. Hence, apartment owners who are part of the homeowners association will often have to make votes concerning the implementation of portable PV panels [12].

   However, the systems offered can be categorized as privacy screens, which are widely accepted on balconies, as evidenced by numerous installations taking place on apartments owned by housing associations, as observed in Figure X. Consequently, homeowners' associations (Vve) and tenants can come to an agreement upon the installation of such systems without requiring permits. It is important to note that these associations have the authority to impose these regulations independently of government laws, indicating the possibility of ignoring the permit stipulations.

After receiving permission from the Owners' Association and the landlords, the tenant must notify the network administrator before the installation of the system and must register on the `www.energieleveren.nl` website to inform the grid operators and the energy suppliers about generating electricity [17]. In addition, solar PV systems in the Netherlands must comply with the technical requirements to check if the installed electricity meter is suitable [60].

Subsidies and Incentives

To support individuals, businesses, and organizations in the adoption of solar PV projects and embrace sustainable energy practices, the government uses financial subsidies and incentives. These incentives promote solar adoption and can be offered to specific groups of individuals and businesses. Here are the main subsidies and incentives offered by the Dutch Government to encourage to adoption of residential solar systems:

1. **Energy Tax Rebate** An energy tax rebate, also known as an energy tax credit, is a financial incentive provided by the government to encourage investments in renewable energy technologies. These rebates come in the form of a reduction in the amount of taxes owed to the government. For example, the Environmental Investment Deduction (MIA) allows deductions of up to 45% of investment costs and the Arbitrary Depreciation of Environmental Investments (Vamil) offers the possibility to write off 75% of the investment expenses for investors [99]. Additionally, the Energy Investment Allowance (EIA) offers a deduction of 45.5% on investment costs for investors in energy-efficient and renewable technologies.

2. **Green Loans**

   Green loans are a variety of loans offered for residents willing to invest in sustainable energy solutions such as solar panels [150].

3. **Local Subsidies**

   Aside from national scheme subsidies, municipalities offer local subsidies depending on the region. For example, the province of South Holland launched "Sunny South Holland", a subsidy scheme that offered more than four million euros to boost the adoption of solar panels on large roofs [106] [150] [91].

After listing the main subsidies and regulations imposed by the Dutch government, it is essential to highlight their main impacts on the Dutch residential solar market.

Impact of Regulations and Policies

The regulations and subsidies imposed by the Dutch government had a substantial impact on the adoption of residential PV. For example, the net metering policy played a crucial role in the rapid expansion and diffusion of residential solar PV [57]. This claim was also supported by a report issued by Algemeen Nederlands Persbureau also known as ANP (2023) which showed that unprecedented growth in the number of installed residential solar was observed [83]. Net metering was therefore found to be a major driver of the residential solar PV market. Other subsidies showed that the acceptance of individuals and homeowners into the subsidy program led to an increase of about 14.4% in the probability of installing solar PV systems [63]. In addition, this study showed that the arrangement of subsidies led to a larger installation capacity of 33.2% with adoption of one year earlier.

On the other hand, the uncertainty in policies and the introduction of new regulations by the government also play a crucial role in posing a threat to new entrants in the residential solar PV market. For example, the proposal to abruptly end the net metering scheme significantly lowered the demand for solar energy systems [6].

Recently, the government and the municipalities have announced slowly withdrawing from providing supportive subsidies due to the profitability of solar PV systems without the need for subsidies and incentives [106] [102]. However, this would not directly affect end-users adopting portable PVs under the PaaS business model since their systems are owned by the energy company providing the service. In addition, entrepreneurs implementing portable PV systems under the PaaS business model have access to a broader range of subsidies such as HER+, and NICE which are granted to entrepreneurs who innovate and invest in sustainability [106].

Economic Factors

One main factor that influences the adoption of renewable energy technologies in a country is the wholesale price of electricity. The graph provided by Statista (2024) representing the electricity wholesale prices from 2019 to 2023 shows prices in the range between 20 and 80 €/MWh before 2021. However, following Russia's invasion of Ukraine in February 2022, electricity prices peaked at 447 €/MWh in August 2022 [124] [30]. At the start of 2023, prices started to decline gradually reaching 73 €/MWh in December 2023, marking the lowest electricity price in the Netherlands since mid-2021.

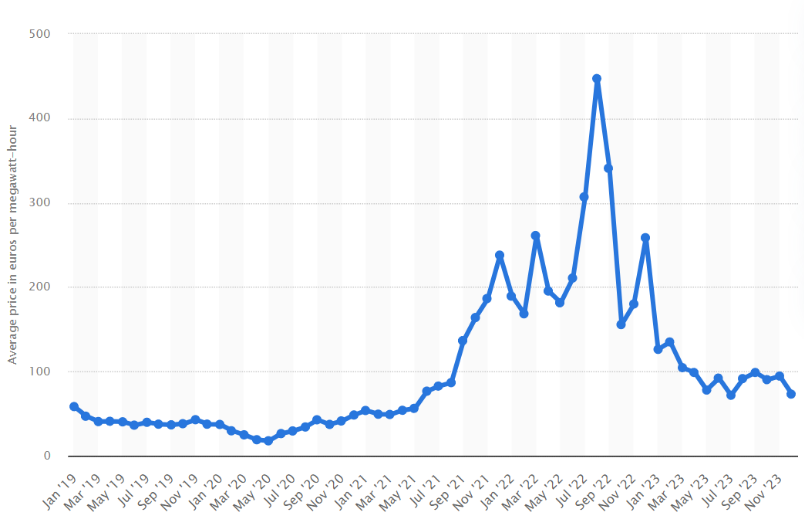


Figure 3.19: Average monthly electricity wholesale price in the Netherlands from January 2019 to December 2023 [123]

To protect consumers from unusual electricity prices, the government introduced an electricity price cap to the market at 0.4 euros/kWh in 2023. This means under a determined electricity consumption value, consumers will not pay more than the price cap of the market [33] [50]. Recently, the price has stabilized at around 35€/MWh which is higher than before the energy crisis but relatively lower than previous years [88]. This is mainly due to the increase in gas supply from other countries, and the reduction in energy suppliers' prices after the introduction of energy tax rebates. In addition, the Dutch government doubled its effort in building LNG (liquid gas) terminals to lower their dependence on Russian gas [32] [87]. Introducing these measures relieved the panic in the market and is supposed to ensure stable prices without major fluctuations like the ones observed in 2022. Unfortunately, geopolitical tensions in the Middle East and Ukraine are still ongoing and can have a major impact on the market at any moment. Hence, if conflicts arise, a major influence on the electricity forecasts in the future will be observed. In addition, according to the PBL, Netherlands Environmental Assessment Agency, electricity prices can either increase or decrease in the future depending on the development of electricity consumption and rates in 2030 [88]. However, based on the observations of energy market experts, the electricity market should not reach the peaks observed in the last couple of years since the issue is getting significant attention from the government and measures are being taken to prevent potential crises [88].

Another key factor affecting the residential solar PV market is the Levelized Cost of Electricity (LCOE) which is a metric that calculates the cost of generating electricity from a particular energy source over its lifetime. This metric takes into account capital expenditures, operation and maintenance costs, and fuel costs and divides them by the total electricity generated by the system over the same period. It is expressed as the cost per unit of electricity (e.g., €/KWh) and is used to compare the cost of generating electricity using different energy sources. According to Figure 3.20, solar PV systems were ranked second in terms of LCOE in 2022-2023, achieving a lower LCOE than all currently used electricity sources except onshore wind. This indicates that solar PV systems can be categorized as one of the cheapest sources of electricity, hence making them attractive to consumers wishing to adopt renewable energy solutions.

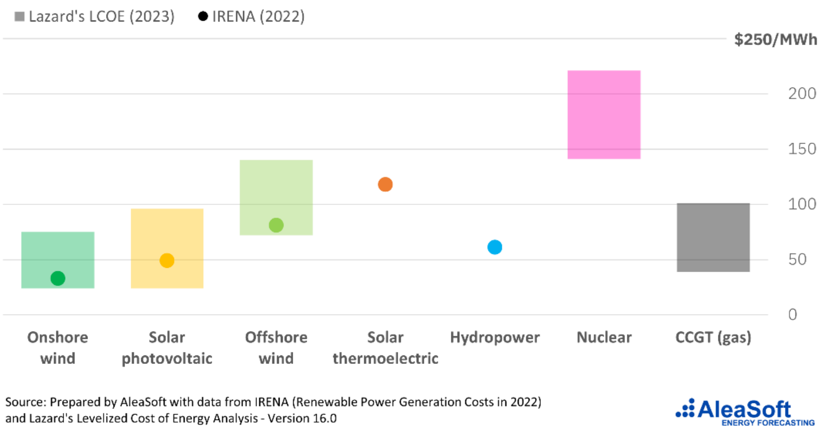


Figure 3.20: LCOE of Different Electricity Sources 2022-2023 [3]

To better understand LCOE trends, it is important to understand the current and future fluctuations in investment expenditures. For example, a joint study conducted by the Netherlands Enterprise Agency (RVO), TKI Urban Energy, Top Sector Energy, and FME indicated that the manufacturing costs of solar panels will be half its current value in 2030 [104].

The International Energy Agency (IEA) also mentioned that the innovations taking place in the solar PV sector will lead to further reduced costs of solar modules and other components, hence increasing the competition with fossil fuel power plants [54].

Additional forecasts from the Energy Transition Outlook report for the year 2023 issued by the risk management company DNV indicated that PV investment costs currently at 0.8€/Wp are expected to decline to 0.64 €/Wp in 2030 to finally reach 0.51 €/Wp in 2050 [23].

These forecasted figures might differ from one source to another depending on the components of the PV system, however, all these sources indicate a decrease in the cost of solar modules and the CAPEX of solar systems. The reductions in CAPEX costs have a direct effect on the average solar LCOE. Additionally, the European Technology and Innovation Platform for Photovoltaics (ETIP PV) conducted LCOE calculations for multiple European countries and revealed an expected 50% decline in solar PV's LCOE in 2050 [39]. The Energy Transition Outlook report for the year 2023 issued by DNV also predicted a solar LCOE of 0.019 €/kWh in 2050 as indicated by Figure 3.21 [23].

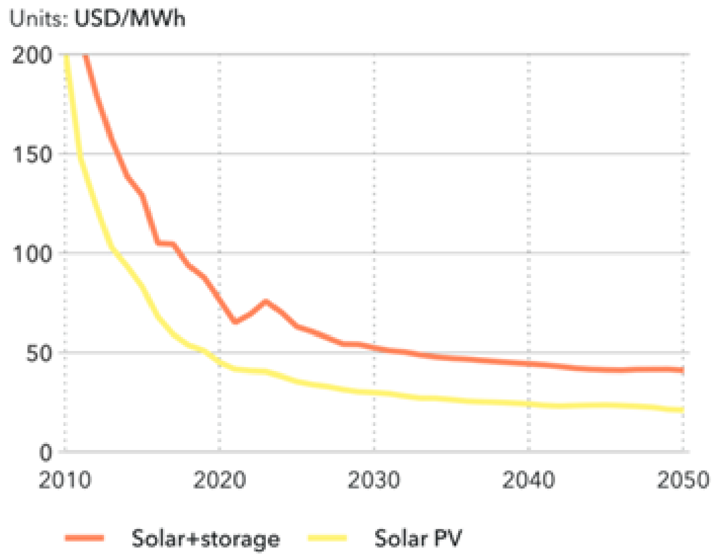


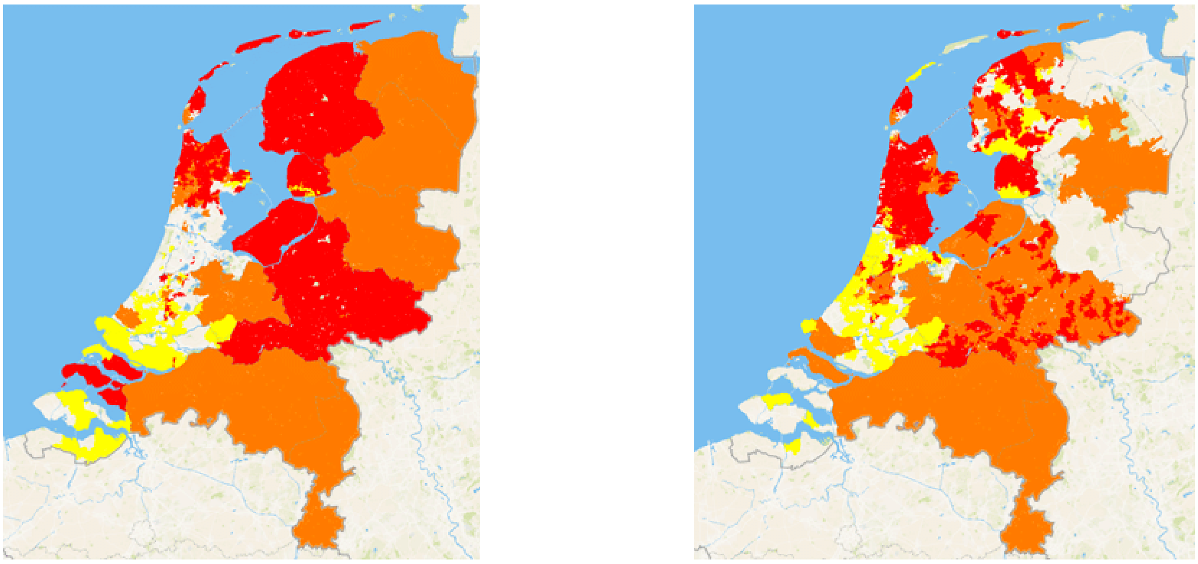
Figure 3.21: World Average LCOE of Solar Energy 2010-2050 [23]

Consequently, the uncertainty dominating the electricity market and the low and decreasing levelized cost of electricity for solar systems motivate the government and consumers to strive for energy independence by integrating solar PV systems.

Technological Advancements and Infrastructure Developments

One of the main technological factors influencing the residential PV market is the advancement in solar panels' efficiency. A breakthrough in solar panel efficiency has been observed lately with the development of perovskite tandem solar cells. The combination of perovskite material with silicon has demonstrated higher efficiency values by allowing solar panels to enhance their absorption capabilities. Consequently allowing residents to generate more electricity than conventional solar cells and at a lower cost [73] [97]. Moreover, the solar PV industry is putting substantial efforts into enhancing PV panels' circularity, thus making solar PV more attractive for customers willing to use sustainable energy technologies. For example, Biosphere Solar, a Dutch start-up company is working on designing modular PV modules [113].

In terms of infrastructure, many challenges related to grid congestion are threatening the country. In fact, with the ongoing electrification in the Netherlands and the increase in the capacity of distributed renewable energy systems such as wind and solar systems, the country is facing a significant limitation in the utility grid capacity. This was highlighted by Figure 3.22 provided by Netbeheer Nederland (2024), which shows the feed-in and supply of electricity to the grid in different regions in the Netherlands, where the orange and red colors indicate limited transport capacity in the grid. Hence, although grid operators are installing hundreds of new transformers and thousands of kilometers of new cables, the current pace is not enough to cover the electricity demand of the country [18].



(a) Grid Congestion Feed-in in the Netherlands

(b) Grid Congestion Supply in the Netherlands

Figure 3.22: Grid Congestion Feed-in and Supply in the Netherlands [18]

Moreover, according to the transmission system operator, TenneT, the Dutch grid electricity is congested, and the demand for electricity from the high-voltage grid is higher than the supply hence urging the company to expand its grid for the coming years [133]. The Dutch utility grid operator Liander also added that grid capacity is not guaranteed and that the country should work on increasing the pace of improving the grid due to the high-volume capacities of solar systems being implemented in the coming years [28]. ABN AMRO Bank also predicted the demand for electricity to double in 2050 causing even more stress on the grid. The Bank also mentioned that the grid is expanding at a slow rate due to the delayed permit processes and the absence of qualified technicians [5].

Even though the electricity grid capacity is not expanding at the required rate, many efforts are being invested to allow for short-term grid solutions. For example, Liander has implemented bottlenecks limiting the number of renewables integrated into the grid [28]. Also, TenneT in collaboration with Alliander, Stedin, and Enexis established a national action program, the ”landelijk actieprogramma” in 2023 to accelerate grid investments and develop solutions for the grid problem [134]. In addition, the total investment in the grid is currently €5 billion per year and is expected to reach €8 billion per year, starting in 2025 [132]. It is important to mention that end-users implementing portable PV systems on their properties are not affected by the grid congestion problem. In fact, at the European level, the trivial limit for balcony PVs introduced by the VDE is 800W, as previously discussed in section 3.3.4. Hence, according to the same source, solar PV systems with a capacity of up to 800W are no longer considered grid-relevant from the point of view of grid operators. As a result, the integration of portable PV systems is expected to gain wider acceptance in the residential sector due to its minimal impact on grid congestion compared to rooftop PV and other renewable energy systems.

Furthermore, the development of new technologies and products allows for the expansion of the market by targeting previously unexplored customer segments. For example, portable PVs opened a door for renters and apartment residents allowing them to generate solar electricity without the need for large mounting spaces.

Social Influences

Social influences substantially affect the opinion of residents in adopting solar PV systems in their dwellings. For instance, a study conducted by Statistics Netherlands (CBS) showed that 75% of the population is worried about future generations being affected by climate change and a substantial majority want to support the transition from fossil fuels to greener energy sources [125]. Specifically, solar energy recorded the largest support with 83% of participants demanding an increase in its adoption, indicating the largest share of public opinion compared to other energy sources as indicated by Figure 3.23.

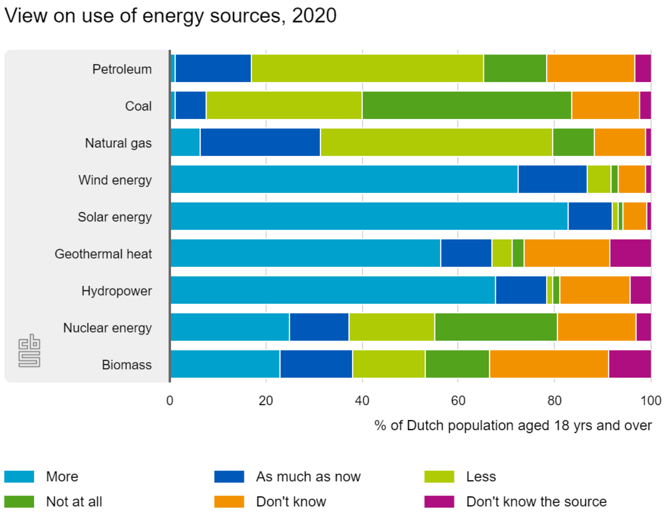


Figure 3.23: Public Opinion of Dutch Citizens Concerning Different Energy Sources [125]

Another report shared by the government indicated that around 67% of people in the Netherlands agree on the urgent need to take action concerning climate change reflecting that there is no lack of public awareness regarding climate change in the country [81].

Moreover, the government is initiating programs to encourage incorporating sustainability in different sectors such as education, science, and culture. This further increases public awareness and knowledge about the dangers of climate change [49].

In addition, environmental advocacy groups in the Netherlands such as Milieudefensie, and Friends of the Earth International are essential in promoting sustainability and shaping environmental policies and practices in the Netherlands through public awareness efforts, lobbying for policies, and legal initiatives [77] [72].

All the efforts posed by the government, advocacy groups, educational institutions, and the energy market improve public awareness and push the actors in this market to search for sustainable energy technologies and practices. This triggers electricity consumers to adopt solar PV systems due to their affordability and ease of installation, particularly for residential properties.

On the other hand, it is important to mention that previously mentioned technological, economic, and regulatory factors can have a significant role in increasing consumers' behavior uncertainty. In fact, a change in consumer behavior and demand can impact the financial returns predicted by the company. For example, a report published by ING Research (2023) indicated that according to the online search behavior of consumers, a fall in consumer demand for solar systems was a result of a decrease in wholesale electricity prices and the decision to phase out net metering. The opposite observation was seen when electricity prices underwent a sharp rise [84]. In addition, according to the same source, an increase of 15 to 20 % in demand for solar PV systems was observed for the first quarters of 2023, however, this was followed by a drop of more than 14% in the last quarter of the same year. This further indicates the unexpected change in consumer behavior and demand for solar PV energy systems caused by numerous social, financial, and regulatory factors.

3.3.5. Main takeaways

After analyzing the competitive and consumer landscapes, and identifying the external factors affecting the Dutch residential solar market, a SWOT (strengths, weaknesses, opportunities, and threats) analysis is done to outline the main takeaways of the market analysis.

First, the strengths of the product and business model are listed, as shown by Figure 3.24. These strengths represent the competitive advantage of the business model and what distinguishes it from other business models in the market. After identifying the business model's strengths, it is important to mention the weaknesses of the business model. By acknowledging these weaknesses, companies can develop strategies to address these shortcomings and hence improve the overall performance of the business model in the future. The strengths and weaknesses of the business model are not the only factors affecting the performance and success of the business model. In fact, external market factors indicated by the blue and orange quadrants play a crucial role in the development of the business model. For example, the opportunities are favorable factors that create potential areas for growth and expansion in the market. Finally, the threats are challenges and risks posed by the market, currently or in the future and these threats can hinder the development and success of the business model causing it to lose its market share.

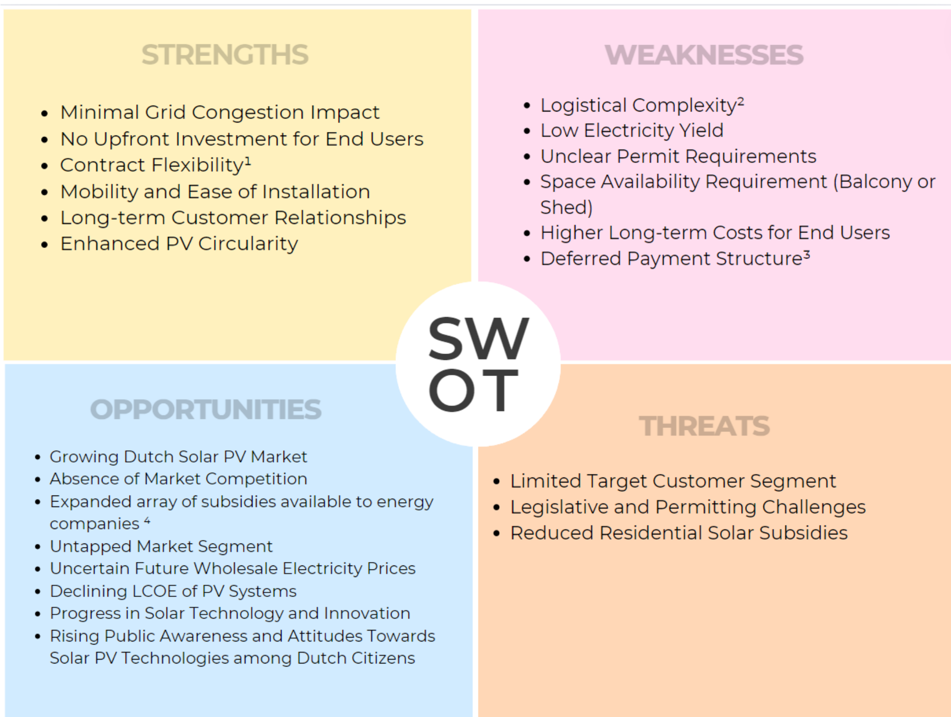


Figure 3.24: SWOT Analysis

1

2

3

4

[1]The ease of installation and mobility of portable PV systems enables the company to offer short-term contracts for its customers, hence eliminating the need for long-term commitments.

[2]This represents the challenge of managing the distribution, maintenance, and retrieval of portable PV systems under the PaaS business model.

[3]This represents the challenge of waiting for subscription payments over time, as opposed to immediate cash flow generated from direct sales.

[4]Companies willing to adopt the PaaS portable PV business model receive a broader range of subsidies than residential end-users.

4
Define

The Define phase converges to define the problem and scope of this study based on insights from the Discover chapter 3. This involves selecting the target segment, as detailed in section 4.1. Next, the chapter outlines primary goals and design directions in section 4.2 forming the basis for the development and evaluation of concepts in Chapter 5.

4.1. Target segment

A key step in developing a business model is to select a target segment, in order to tailor the business model based on their needs and preferences. Based on the findings of section 3.3.3, the target segment selected is **"Apartment Renters with Short-term Contracts"**. This choice was based on the following observations:

- Around 53% of rental properties are apartments [67].
- Less than 1% of rental apartments have installed solar PV systems [125].
- All apartments face space constraints, meaning that only the balcony can be used to install PV systems.

It is worth mentioning that any customer having a balcony or an outdoor space can benefit from the studied business model. However, because of the reasons mentioned above, the PaaS business model for balcony PVs was found to be most suitable for this target segment.

4.2. Goals and design directions

To guarantee the success of the business model, two main goals were identified as shown below.

1. **Encourage target groups to adopt the PaaS balcony PV business model** To achieve this goal, the following design directions were determined.
    - **Financial and Contract Flexibility:** Offer various flexible, cost-effective subscriptions and contract models, in addition to cost-saving expectations and a hassle-free subscription process.
    - **Easy Installation and Removal:** Ensure a lightweight, DIY system with portable features for easy transportation, installation, and removal.
    - **Aesthetics and Customization:** Design an aesthetically appealing system offering customization options for end-users.
    - **Performance and Space Efficiency:** Design the solutions to ensure space efficiency and maximum yield.

2. **Maximize the circularity of the business model** To achieve this goal, the following design directions were determined.
    - **Circularity and Sustainability:** Maximize the panels' lifetime by designing a durable product and employing circular business strategies in the business model.

5

Develop and Deliver

This chapter represents the develop and deliver phases of the double diamond model which involves generating and exploring business model concepts to address the problem. These concepts were generated based on the design directions determined in chapter 4. Additionally, descriptions and 3D digital models are presented to display a clearer representation of the generated concepts. Moreover, this chapter deals with evaluating these concepts based on suggested design criteria to select the winning final design.

5.1. Selection criteria

The suggested concepts will be evaluated using the Harris profile evaluation method based on the design criteria mentioned below. It is worth mentioning that these criteria are outlined in order of importance. These criteria were selected based on the takeaways of chapter 3 and 4. For instance, end-users mentioned their interest is cost-effective, easy to install, space efficient, and aesthetic solutions. In addition, from the perspective of the PaaS service providers, the system should be durable to minimize its material footprint and increase long-term profits. Moreover, the system should be versatile, meaning that it should be integrated into different types of balconies in order to cover a broader range of potential end-users. The feasibility criterion was also selected to assess whether the proposed solution is available in the market, and if not how feasible is it to manufacture.

- **Feasibility:** Refers to the manufacturing and technical feasibility of the concept.
- **Levelized Cost of Electricity:** Measures the cost of electricity generated by a system over its lifetime accounting for the time value of money, as explained in sections 2 and appendix E.
- **Units Per Balcony:** Estimates the number of units of each concept that can be installed on a regular-sized apartment balcony.
- **Durability:** Considers the robustness and longevity of the product over time.
- **Installation and Mobility:** Evaluates the system's design for ease of assembly, transportation, and disassembly.
- **Value Proposition:** Refers to the unique value each product provides to customers.
- **Aesthetics:** Evaluates the aesthetic appeal of the system and its ability to enhance and blend with existing structures.
- **Versatility:** Evaluates the ability of the concept to adapt to different types of balconies.

5.2. Ideation and conceptualization

In this section, numerous concepts and business models are generated based on the previously mentioned design directions as detailed by the conceptualization mind map in Appendix G. These concepts

5.2.1. Lightweight Balcony Railing PV

This concept is built around the use of lightweight monocrystalline PV panels designed for easy DIY installation to balcony railings using tie wraps and cable ties. The concept offers an attractive solution for renters with short-term contracts looking for a system with easy installation and mobility features.

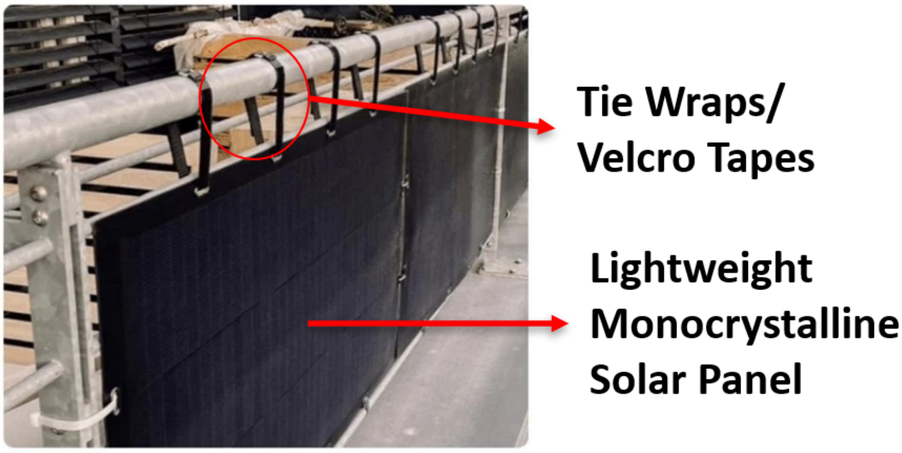


Figure 5.1: Lightweight Balcony Railing PV Concept

- **Feasibility**

  This system is highly feasible as it is being implemented in Europe, especially in Germany. The company ”We Do Solar”, discussed in section 3.3.2, relies on this design of balcony solar PV systems.
- **Levelized Cost of Electricity**

  The price of lightweight mono-crystalline PV panels ranges from 0.81 to 1,25 euros per Wp (depending on the manufacturer), which is higher than conventional rigid monocrystalline solar panels [143] [98]. This is mainly caused by the fact that flexible monocrystalline solar panels are still a niche market. In addition, the system has a low durability meaning that it should be replaced more frequently compared to other concepts that use mainstream panels. Taking into consideration the electricity yield estimates presented in Appendix D and the cost and lifespan value indicated in Appendix E, the LCOE was found to be 0.1 euros/kWh.
- **Units/Balcony**

  This product has smaller dimensions than mainstream solar panels and is installed on the railing, meaning that the balcony railing can be efficiently covered.
- **Durability**

  This concept falls short on durability, as the panels are not contained inside a rigid frame, hence preventing them from withstanding harsh weather conditions and frequent removals and installations [69]. These panels usually last around 15 years, compared to approximately 30 years for regular solar panels [21]. In addition, the mounting structure consists of tie wraps with an estimated durability of 5-10 years depending on the type which further affects the durability of the system [149].
- **Installation and Mobility**

  The main advantages of this concept are its lightweight and ease of installation, as the panels used are the lightest in the market with a weight of around 1.3 kg, depending on the manufacturer [144] [1]. In addition, these panels are usually perforated, allowing them to be easily attached to balcony railings without the need for a rigid mounting structure.

- **Value Proposition**

  This system offers easy-to-install, transport, and remove features that are suitable for end-users who want to avoid the hassle of complex installation.
- **Aesthetics**

  This concept offers sleek black surface solar panels, granting the system a sleek and uniform look. However, the use of cable ties detracts from the aesthetics of the system, and the flexible nature of the panels makes it more complex to integrate vegetation and other aesthetic enhancements to cover the back of the railing.
- **Versatility**

  This product can be placed on any balcony with perforated railing, making it compatible with a wide range of balconies. However, it cannot be installed on glass and other non-perforated railings.

5.2.2. Oriented Balcony Railing PV

This concept is mainly aimed at target groups interested in maximizing the energy yield of the PV system in return for a trade-off with its aesthetic appearance and ease of installation. This concept uses high-efficiency PV panels that are placed on an oriented mounting structure to allow for maximum energy absorption. Figure 5.2 displays a 3D representation of the generated concept.

Figure 5.2: Oriented Balcony Railing PV Concept

- **Feasibility**

  This type of balcony railing PV system is currently the most commonly used design in the balcony PV industry. In fact, it is manufactured by numerous companies and is widely used in Europe, making it a feasible system.
- **Levelized Cost of Electricity**

  The panels used in this concept consist of monocrystalline solar cells which usually cost 0.13 euros per Wp, making them cheaper compared to the lightweight panels in Concept 1 [93]. In addition to the PV panel, the price of the mounting structure should be considered, which is usually between 45 and 90 euros depending on the design and material used [103]. Taking into consideration the electricity yield estimates for this concept presented in Appendix D and the cost and lifespan value indicated in Appendix E, the LCOE was found to be 0.04 euros/kWh.

- **Units/Balcony**

  The large size of the modules and the heavy nature of the system pose an obstacle, preventing the end-users from making efficient use of their balcony space as it is hard to fit this type of system on the edges of a balcony. However, this issue can be addressed by using smaller solar panels (e.g. 36 solar cells).
- **Durability**

  The system is exceptional when it comes to durability, as the solar cells are contained in a frame making them last around 25 to 30 years. In addition, the mounting structure is rigid and made of heavy-duty materials allowing it to last around 20 years which further enhances the durability of the system [43].
- **Installation and Mobility**

  The panels used in this concept usually weigh around 8 to 22 kg depending on the size and number of cells in the panel [40]. In addition, the mounting structure typically weighs between 1.7 to 6.3 kg. Consequently, the balcony PV system is heavy which makes it hard to install, remove, and transport.
- **Value Proposition**

  This concept allows its customers to maximize their electricity production, leading to higher cost savings.
- **Aesthetics**

  This concept falls short on aesthetics, as the oriented mounting structure and solar panels are bulky, exposed, and hard to fit with the environment.
- **Versatility**

  These systems are more restrictive, as they can only be placed on perforated metal or iron railings that can withstand the heavy load of the system.

5.2.3. Privacy Plant PV Stand

This concept is based on the use of a PV stand with easy DIY assembly to generate electricity. This system can be placed as a free-standing unit with wheels or an attachment to the railing extension. In addition, vegetation can be incorporated into the design to enhance the visual appeal and aesthetics of the balcony, as demonstrated in figure 5.3. The panel on the stand acts as a privacy screen, allowing people to hide certain parts of their balconies while maintaining an aesthetic look.

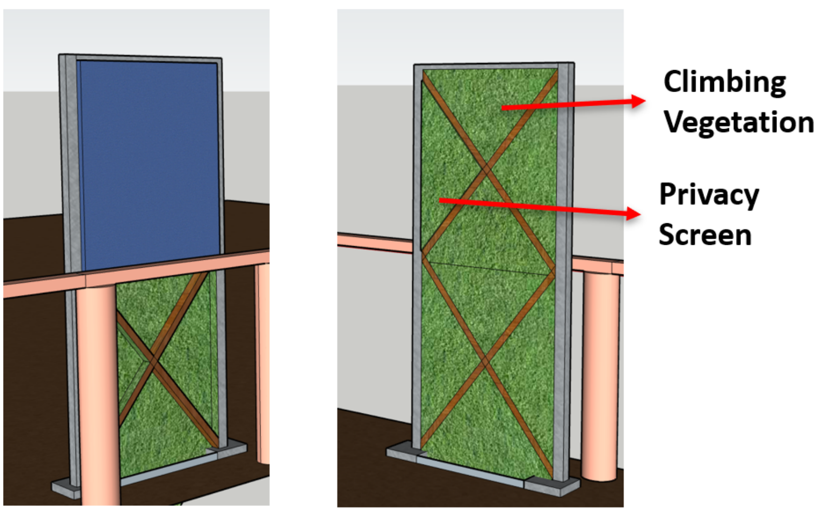


Figure 5.3: Privacy Plant PV Stand Concept

- **Feasibility**

  The suggested concept utilizes an existing outdoor plant stand, widely supplied by home decor manufacturers. Therefore, this system is moderately feasible, as it utilizes accessible components but still requires additional adjustments.

- **Levelized Cost of Electricity**

  The main price drawback of this concept is its high cost. The stand must hold both the solar module as well as any vegetation placed on its back. Moreover, it must withstand the strong winds and harsh weather conditions of the Netherlands. This means that the system should be heavy and robust, which equates to an approximate cost of 110 euros. The PV panel used is a regular PV panel with a price of 0.13 euros/Wp [93]. Taking into consideration the electricity yield estimates for this concept presented in Appendix D and the cost and lifespan value indicated in Appendix E, the the LCOE was found to be 0.15 euros/kWh.

- **Units/Balcony**

  This concept is hard to scale up, meaning that only a few units can be installed on the same balcony as its implementation blocks part of it. Consequently, the system might be difficult to fit on smaller-sized balconies.

- **Durability**

  The system's durability mainly depends on the material used for the mounting structure. Consequently, with the use of durable materials, the system can reach a lifespan of 25 years.

- **Installation and Mobility**

  This concept is made of pre-assembled parts and offers easy DIY features. However, its heavy weight and large size make it complex to move and transport.

- **Value Proposition**

  This system offers a strong value proposition for customers interested in generating electricity while benefiting from an aesthetic privacy screen.

- **Aesthetics**

  One of the main advantages of this system is its aesthetics since it integrates vegetation and plants that cover the system which enhances the overall look of the balcony.

- **Versatility**

  As this concept can be either attached to the railings or incorporated into a standing unit, it can be applied to any space location such as a balcony, terrace, or any outdoor space exposed to the sun's radiation. However, its height blocks part of the balcony, making it harder to install on smaller-sized balconies.

5.2.4. Table PV

This concept makes use of the balcony space efficiently by integrating a PV panel into a table. This allows customers to use the table when needed while being able to generate electricity. To make the system easier to install and move, a foldable feature can be added to ensure easy DIY assembly.

Figure 5.4: Table PV Concept

- **Feasibility**

  This system is moderately feasible, as it only requires a supporting table structure that can hold the panel horizontally as indicated in figure 5.4. In addition, this concept is sold by multiple manufacturers that offer solar PV solutions to the residential sector.
- **Levelized Cost of Electricity**

  The price of this table depends on its size, design, and material used. However, if the panels used are mainstream, the cost of the system would be low. The electricity generated by this system mainly depends on the frequency of usage, shading caused by the upper balcony, and other components on the balcony. Taking into consideration the electricity yield estimates for this concept presented in Appendix D and the cost and lifespan value indicated in Appendix E, the LCOE was found to be 0.1 euros/kWh.
- **Units/Balcony**

  The main disadvantage of this concept is that usually only one unit can be installed on the same balcony, as one table is enough to satisfy the needs of the consumers. Hence, limiting the electricity yield of the system.
- **Durability**

  Given that the table serves multiple functions, including dining, and other uses, its durability could be compromised. For example, if an object were to fall onto it, there is a risk of damaging or breaking the panel. Consequently, these factors can significantly affect the panel's durability.
- **Installation and Mobility**

  The table can be designed to be lightweight and easy to assemble and install, promoting DIY installation and removal by end-users. However, the heavy weight of the panel prevents this concept from attaining a full score compared to other concepts.
- **Value Proposition**

  This system can be used to fulfill all the table's uses and at the same time generate electricity, allowing it to have a strong value proposition.
- **Aesthetics**

  The aesthetics of the system highly depend on the shape and design of the supporting structure and the panel. If these components are chosen carefully, the system can achieve a good aesthetic appearance.
- **Versatility**

  This table is designed to be placed in any outdoor space that receives sunlight, offering a versatile solution. However, its size might make it more challenging to fit on smaller apartment balconies.

5.2.5. PV Shed

This concept introduces a shed or stand equipped with a PV panel, designed as a stand-alone unit attached to the railing. This product serves a dual purpose: to provide shade and generate electricity. Additionally, this concept can be adjusted manually toward the sun's orientation.

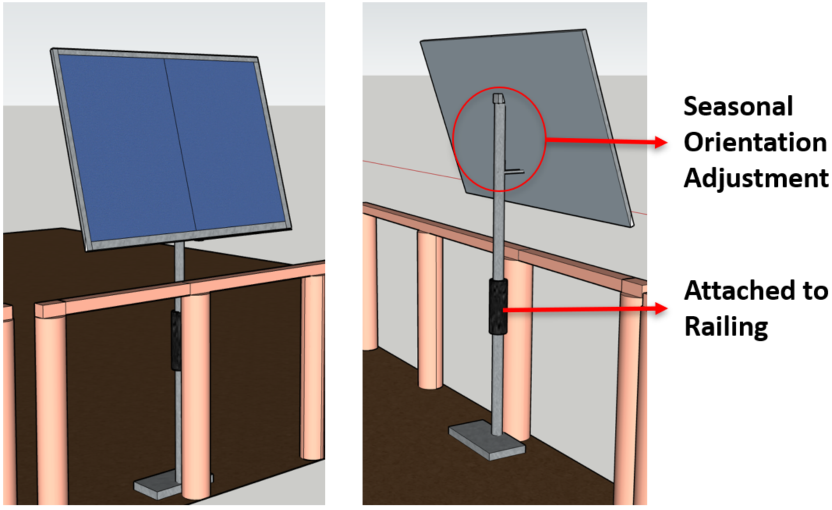


Figure 5.5: PV Shed Concept

- **Feasibility**
  This concept is conceptual and is not present in the markets, preventing it from receiving a positive score. However, it is still feasible to manufacture by requires more effort and planning.
- **Price/Cost**
  The panels used in this concept are regular rigid solar panels, meaning that they cost on average 0.13 euros per Wp [93]. On the other hand, to vertically hold the panel, the system must ensure a robust and resilient mounting structure to ensure that the system can withstand high wind speeds, which adds to the cost of the system. Taking into consideration the electricity yield estimates for this concept presented in Appendix D and the cost and lifespan value indicated in Appendix E, the LCOE was found to be 0.09 euros/kWh.
- **Units/Balcony**
  Only one to two systems can be installed on a regular-sized balcony.
- **Durability**
  The system's durability mainly depends on the material used for the supporting mounting structure. However, the system relies on using an orientable mounting structure at the back of the panel, hence reducing its durability.
- **Installation and Mobility**
  This concept is made of pre-assembled parts and offers easy DIY features. However, its heavy weight and large size add significant complexity to its mobility.
- **Value Proposition**
  This concept offers maximum electricity yield due to its seasonal optimal tilt in combination with the shed and privacy features.
- **Aesthetics**
  This system scores low on aesthetics as it only consists of a stand and a PV panel, making it hard to incorporate any aesthetic enhancements.
- **Versatility**
  As this concept can be either attached to the railings or incorporated into a standing unit, it can be applied to any type of balcony. However, it is hard to fit on small-sized balconies as it blocks a significant part of it.

Lightweight Balcony Railing PV				
Criteria	**Score**			
	- -	-	+	+ +
Feasibility			■	■
Cost of Electricity		■		
Units/Balcony			■	■
Durability	■	■		
Installation and Mobility			■	■
Value Proposition		■		
Aesthetics			■	
Versatility			■	

Oriented Balcony Railing PV				
Criteria	**Score**			
	- -	-	+	+ +
Feasibility			■	■
Cost of Electricity			■	■
Units/Balcony			■	
Durability			■	■
Installation and Mobility	■	■		
Value Proposition		■		
Aesthetics	■	■		
Versatility		■		

Privacy-Plant PV Stand				
Criteria	**Score**			
	- -	-	+	+ +
Feasibility			■	
Cost of Electricity	■	■		
Units/Balcony		■		
Durability			■	
Installation and Mobility	■	■		
Value Proposition			■	■
Aesthetics			■	■
Versatility			■	

Table PV				
Criteria	**Score**			
	- -	-	+	+ +
Feasibility			■	
Cost of Electricity		■		
Units/Balcony	■	■		
Durability		■		
Installation and Mobility			■	
Value Proposition			■	■
Aesthetics			■	
Versatility			■	

PV Shed				
Criteria	**Score**			
	- -	-	+	+ +
Feasibility		■		
Cost of Electricity			■	
Units/Balcony		■		
Durability		■		
Installation and Mobility		■		
Value Proposition			■	
Aesthetics		■		
Versatility			■	

Figure 5.6: Harris Profile of Generated Concepts

Based on the Harris profile evaluation, the ”Table PV” and ”PV Shed” concepts were eliminated as they failed to meet the most important criteria such as feasibility, cost of electricity, space efficiency, and durability. Although the ”lightweight balcony railing PV” concept scored well on feasibility, space efficiency, and ease of installation, the concept relies on flexible PV panels which are less durable than regular PV systems. Hence, a combination of the ”Oriented Balcony PV” and ”Privacy Plant Stand” concepts was selected. This combination scores well on all criteria except the installation and mobility, which can be addressed in the mounting structure design stage.

To conclude, a total of five preliminary concepts were developed: **Lightweight Balcony Railing PV, Oriented Balcony Railing PV, Privacy Plant PV Stand, Table PV, PV Shed**. Each of these concepts possesses specific features that differentiate it from the other concepts. Consequently, these concepts were evaluated and a combination of the ”Oriented Balcony PV” and ”Privacy Plant Stand” concepts was selected as the winning final solution.

6
Final Design

This chapter deals in more detail with the final design chosen in chapter 5. First, the product specifications such as PV panels, mounting structures, cables, and inverters are outlined in section 6.2. Next, section 6.3, explores the subscription type adopted in the business model. Then, the cost structure covering both the capital expenditures and operational expenses of the business model is analyzed in section 6.4. The electricity yield is computed to determine the levelized cost of electricity for each subscription plan in section 6.5. Consequently, the pricing scheme model which calculates the subscription fees, cost savings, and profit is developed and explained in section 6.6. Finally, the contract specifications of the business model are established in section 6.7.

6.1. Description

After evaluating the five generated concepts, a final concept was selected. This concept was inspired by the ”Oriented Balcony Railing PV” and the ”Privacy Plant PV Stand” concepts by combining their advantages and addressing their limitations. This concept relies on a “Tiered Subscription Model”, consisting of two subscription plans: the **Basic** and **Privacy** plans. The Basic plan consists of two Basic units as observed in figure 6.1 and 6.3. On the other hand, the Privacy plan consists of one Basic unit and one Add-On unit, as shown in figure 6.2 and 6.3. Hence, users can purchase a base level of service with the option to purchase additional features and services as add-ons for an additional price. This allows users to choose the additional features based on their needs, preferences, and constraints without having to pay for features they don’t find worthy.

6.1.1. Basic Plan

This basic plan targets end-users who are not interested or not feasible to install a privacy screen on their balcony. This basic plan relies on the use of mainstream solar panels with below-standard solar panel sizes. This size allows the system to fit on any type of balcony and ensures that the whole railing system can be efficiently used to generate electricity. The mounting structure that holds the panels consists of a lightweight standing unit with a **10-degree tilt** and a clamped frame where the panel can be integrated, ensuring an easy installation and removal process. This mounting structure is attached to the railing using railing clamp attachments to the mounting structure as indicated in Figure 6.1. In addition, this plan offers aesthetic enhancements for end-users allowing them to add an aesthetic appeal and decoration to their balcony while generating electricity. These aesthetic enhancement options consist of solar skins, climbing vegetation, posters, and other options depending on the customer’s preferences. These enhancements are presented in more detail in section 6.2.

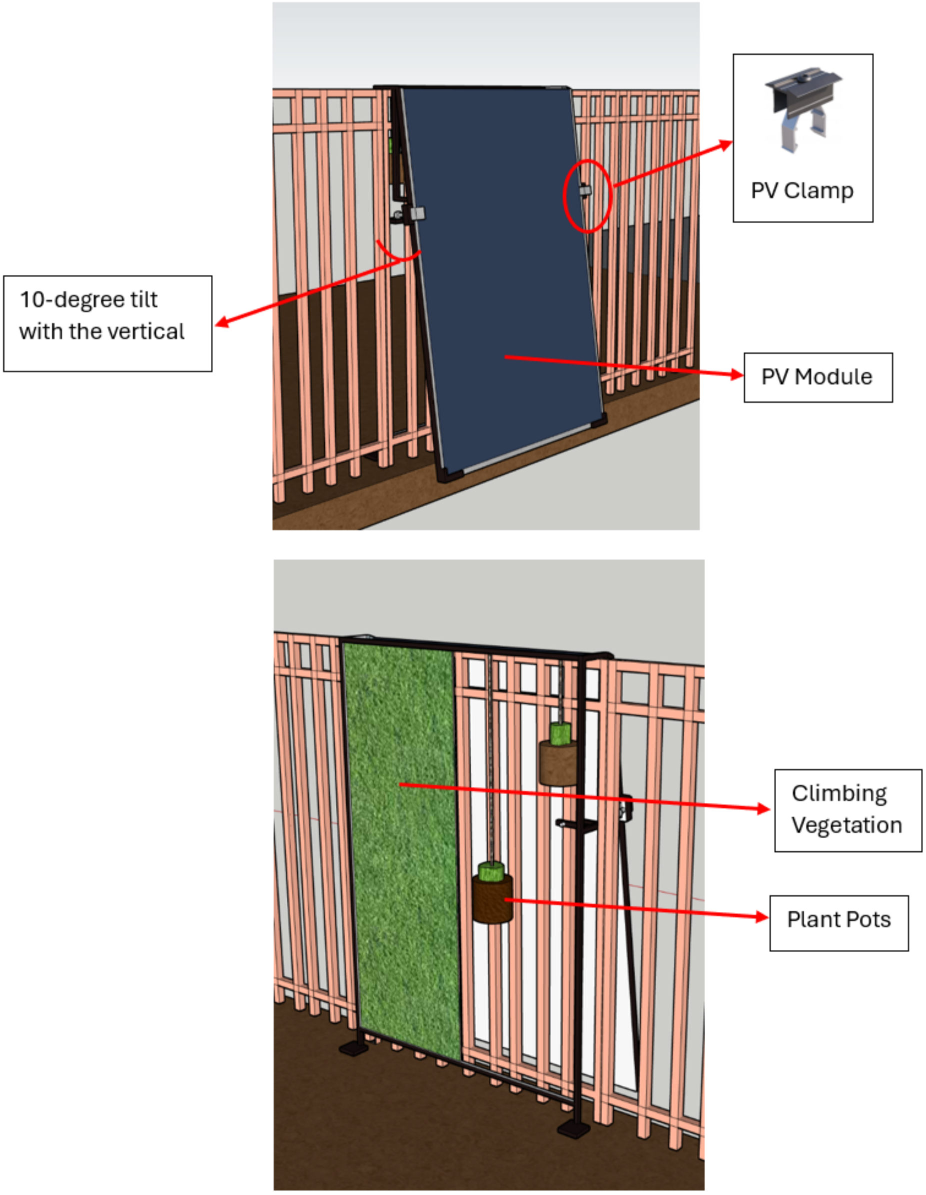


Figure 6.1: Basic Unit

6.1.2. Privacy Plan

This plan targets customers who want to hide some parts of their balcony with a privacy screen while generating additional electricity and enhancing the aesthetics of their balcony space. This panel extension can be easily plugged into the Basic unit, allowing for an easy assembly and installation process. To enhance the aesthetics of the extension, a customizable painting can be added on the back of the extension PV panel as indicated in Figure 6.2.

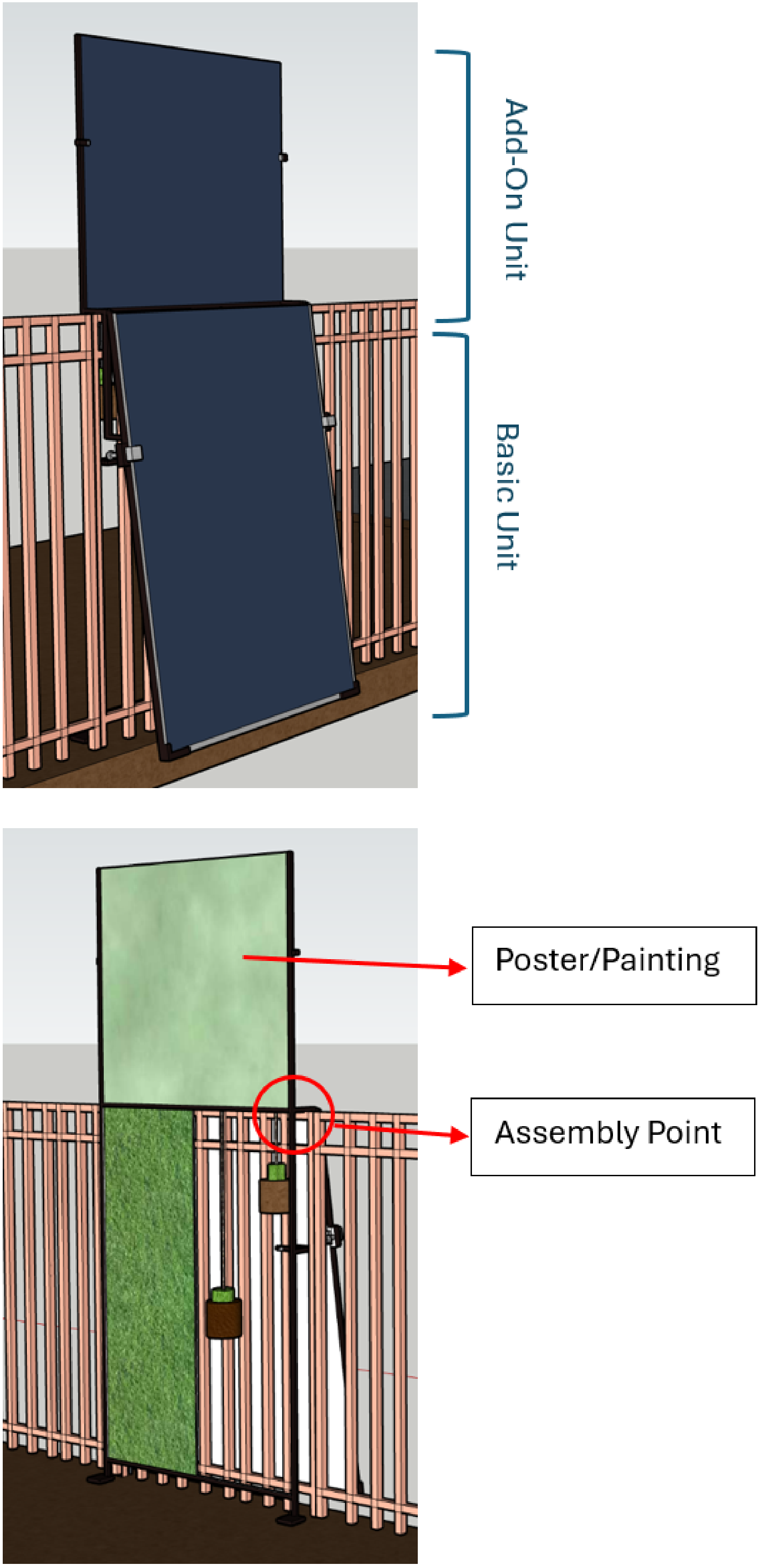


Figure 6.2: Basic and Add-On Units forming the Privacy Plan

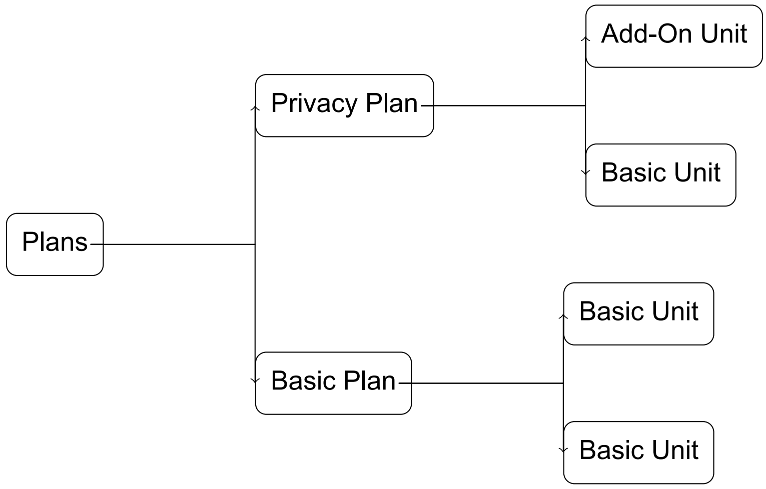


Figure 6.3: Structure of Basic and Privacy Plans

The next step is to delve deeper into developing the business model and product by identifying its product specifications, cost structure, electricity yield, pricing scheme, and contract specifications.

6.2. Product specifications

A crucial step in designing a business model is to select its product specifications. Hence, this section deals with selecting the products covering the main components of the systems such as PV panels, mounting structures, cables, and inverters.

6.2.1. PV Panel

This section deals with selecting the PV technology to be adopted by the business model accounting for all the insights collected from the previous chapters.

First, the PV panel technologies used in the residential solar PV sector were identified. Currently, the three main types of PV cell technologies available in the market are mono-crystalline, poly-crystalline, and thin film, as represented in Figure 6.4. However, it is important to mention that the final concept relies on the use of a framed solar panel with a lifespan of 25 to 30 years, which eliminates the thin film technology from the suggested options.

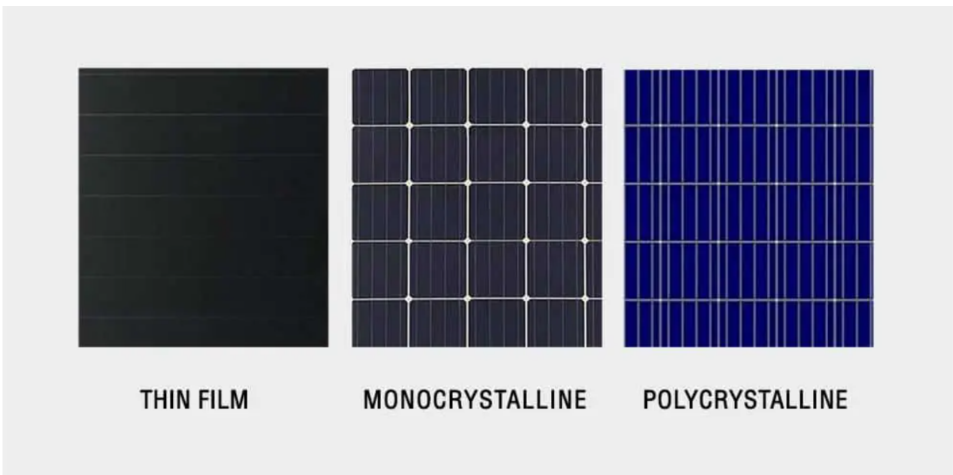


Figure 6.4: Types of Solar Cells [117]

One of the main criteria to look into is the durability and lifespan of the PV module. That is because the PaaS business model requires the solar modules to be removed, installed, and moved frequently and requires a panel that can withstand these actions. In addition, the PV panel's lifespan is a crucial aspect to consider, as this can significantly affect the LCOE of the system. One of the indicators of this aspect is the performance degradation rate which represents the decrease in efficiency as a function of time. To ensure that the panels' performance and efficiency are maximized in the long term, a panel with a low-performance degradation rate should be chosen. In fact, mono-crystalline solar panels are known for their low-performance degradation with an average value ranging between 0.3% to 0.8% per year due to their pure silicon structure [4] [9]. Poly-crystalline cells on the other hand have a slightly higher degradation rate and lower durability compared to mono-crystalline PV cells.

Secondly, installing portable PVs on limited space availability areas such as balconies significantly affects the yield of the PV system. To address this issue solar cells with high efficiencies should be selected to maximize energy generation. Even though the exact efficiency of the solar panels can differ depending on the manufacturer, technology, structure, and material used, approximate values can be deduced. In fact, mono-crystalline solar cells have the highest efficiency due to their pure silicon structure ensuring an approximate efficiency of 17% to 24% compared to an efficiency of 15 to 18% for poly-crystalline [44].

Weight and portability are also important factors to consider as the system will have to be moved frequently affecting its ease of installation and transportation. Mono-crystalline solar panels have a higher energy density (Wattp per Kg) compared to poly-crystalline solar panels as they are more efficient. This means that a smaller and hence lighter mono-crystalline solar panel can generate the same electricity yield compared to a poly-crystalline solar panel.

Finally, according to section 3.3.3, some of the participants of the surveys and interviews mentioned their concern about the effect of solar panels on the property's aesthetics. Taking this concern into account showed that mono-crystalline solar panels have a uniform dark color across the surface, resulting in a visually appealing solar panel compared to poly-crystalline panels that often have a bluish color, bulkier form, and more visible grid lines.

Given that mono-crystalline solar panels offer superior durability, efficiency, and energy density, and aesthetics compared to poly-crystalline solar panels, and knowing that the costs of both types are roughly equivalent, mono-crystalline panels has been selected for use in the final concept.

After researching numerous mono-crystalline solar panels, the Cygnus SP-M10/40H 150W solar panel was chosen as the panel used in the Basic unit. For the Add-On unit, the Cygnus SP-M10/32H 120W panel was selected. These solar panels have respective efficiencies of around 20%.

The Basic unit solar panel ensures an efficient use of the balcony fence, as the dimensions of the panels (LxW) are 990x766 mm making it fit on any balcony fence as the minimum length of a balcony fence in the Netherlands is 1000 mm [42]. The width of the panel also ensures that the panel can fit on the sides of the balcony fence to maximize space efficiency. Moreover, the panel has a lighter weight of 8.3 kg compared to 20-23 kg of regular solar panels. This reduces the weight of the system and makes it easier for the end-users to install, transport, and remove the system. On the other hand, the privacy screen solar panel was chosen carefully to have the same width as the primary solar panels, however, this model has a shorter length of 804 mm to make sure the balcony is not completely blocked and some space exists between the railing and the ceiling.

6.2.2. Inverter

Now that the solar panels have been selected, an AC/DC inverter must be chosen to convert the DC output of the panel to match the alternating current (AC) of the property.

First, it is necessary to choose the type of inverter that will be used. Numerous types of inverters exist:

- Central Inverter
- Micro Inverters
- String Inverters
- Multi-string Inverters
- Team Inverters

Out of all the stated inverters, microinverters were selected for the following benefits and advantages:

- Panel Optimization: These inverters are installed on each solar panel separately. This means that each panel can operate independently of the system and hence maximize its electricity yield. This is suitable for the case of balconies, as they are usually exposed to more shading, caused by the surrounding environment.
- Low Failure Risk: With two panels having one microinverter, the failure of one panel or its inverter does not affect the performance of other parts of the system.
- Modular Design: This type of inverters allows for more flexibility in system expansion.
- Ease of Installation: These inverters are installed separately for each plan which eliminates the need for complex wiring during installation. This is beneficial in the case of DIY installation, as is the case for the final concept adopted.
- Simplified Maintenance: Maintenance and repair of the system is made easier as the units of each plan operate independently. This feature is essential in the PaaS business model, where minimizing maintenance costs is important.

Consequently, each subscription plan will consist of one microinverter. Since the Basic and Privacy plans have a total panel power rating of 300 and 270W, a microinverter with a rating of 350W was selected to account for any additional overproduction. A suitable choice was found to be the Hoymiles single phase 1-in-1 HMS-350-1WB microinverter with a power rating of 350W as indicated in the datasheet found in appendix J.1. In addition, this microinverter includes an MPP Tracker and a 2.4 Wi-Fi monitoring feature allowing all the data to be uploaded to the cloud. This live monitoring feature will serve as a tool for the company to measure the performance of the systems and be notified in case of any malfunction. The microinverter also has a Bluetooth connection option, so end-users can connect using the local Hoymiles Application and monitor their electricity yield. This allows them to accurately estimate their cost savings and check the performance of their systems. Additionally, the electricity yield generated by each system will help in calculating the monthly subscription fee of each end-user, as will discussed in section 6.6.

6.2.3. Mounting Structure

An essential component of the products offered is the mounting structure that will be attached to the railing to support the solar panels. Two structures were designed for each of the Basic and Add-On units, as shown in figures 6.5 and 6.6. This structure has approximate dimensions (L*H*W) equal to 0.8*1.0*0.2 m. As observed in figure 6.5, the panel is attached to the Basic unit's mounting structure using the PV clamps, making it easy to attach the PV panel. In addition, the structure is made from hollow square beams to ensure a lighter weight and relies on two railing attachments to prevent the mounting structure from falling in case of gusty winds. This railing clamp is designed to fit the different spacing and dimensions of the railing bars where the maximum allowed bar spacing is 10 cm [86]. This grants this railing clamp the flexibility to fit on railings with diverse bar spacings and designs. In addition, to prevent the noise caused by the vibration of the mounting structure on the railing, two noise dampers are placed on the point of contact with the railing.

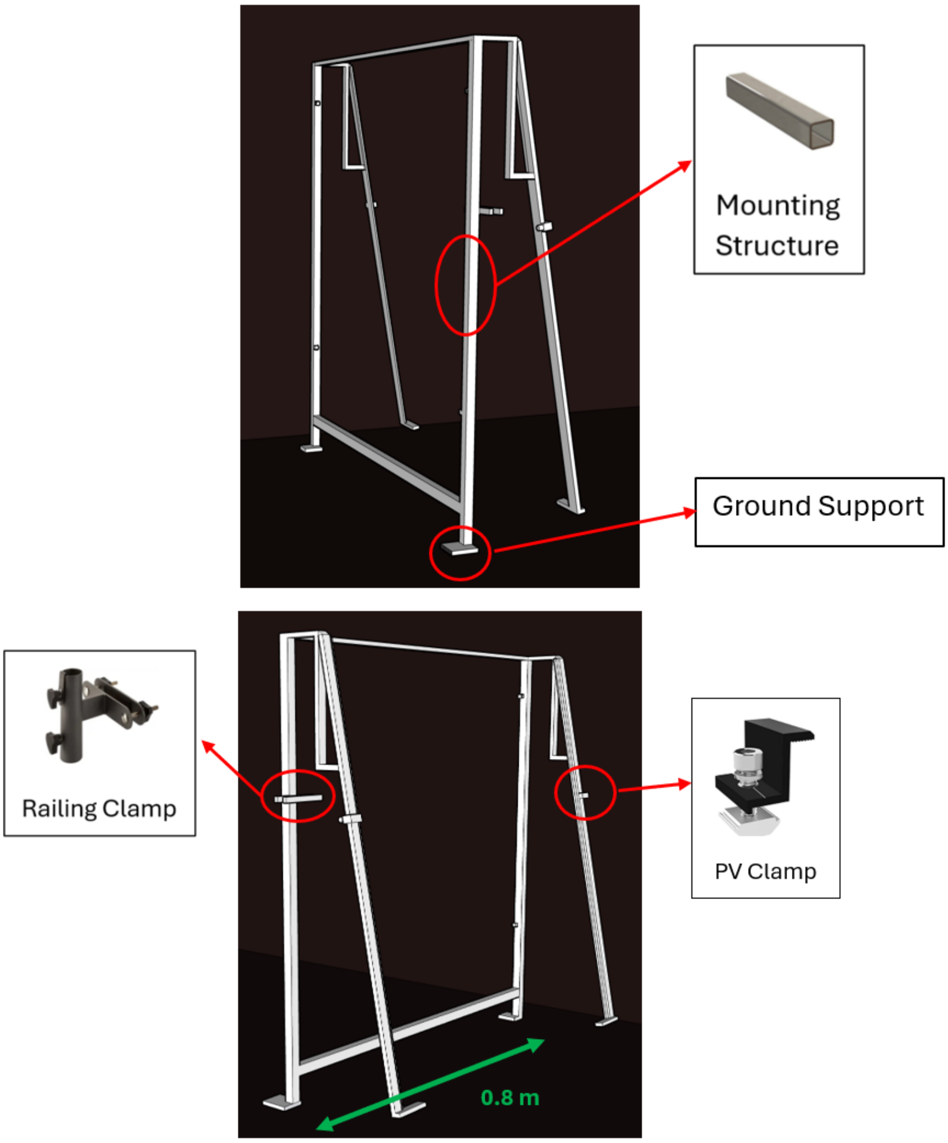


Figure 6.5: Basic Unit Mounting Structure

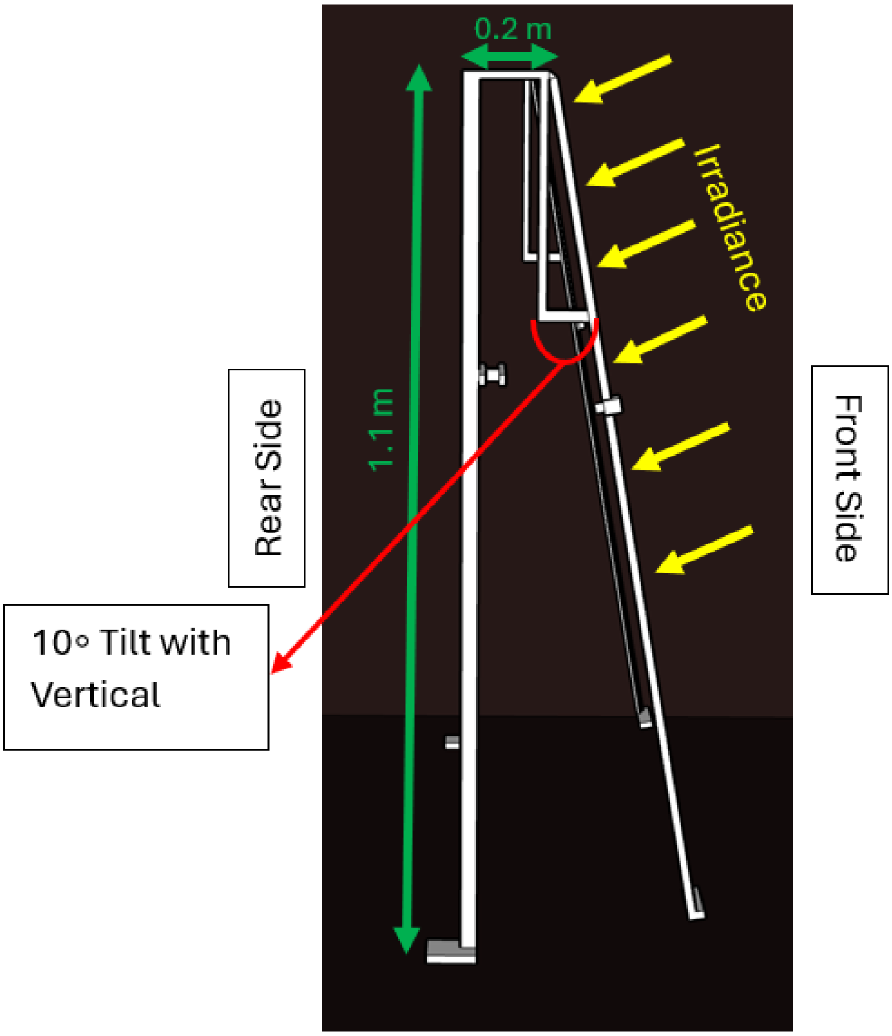


Figure 6.6: Basic Unit Mounting Structure

If the end-user subscribes to the Privacy plan, an additional Add-On mounting structure on which an additional panel is placed is added to the Basic unit's mounting structure, as shown in figure 6.7. The additional structure has a square beam with smaller dimensions allowing it to be inserted at the assembly point. To ensure the upper structure is safely connected and stable, a key connecting the lower and upper beams is used. Additionally, this part has the same length as the base structure; however, it adds 0.81 m in height.

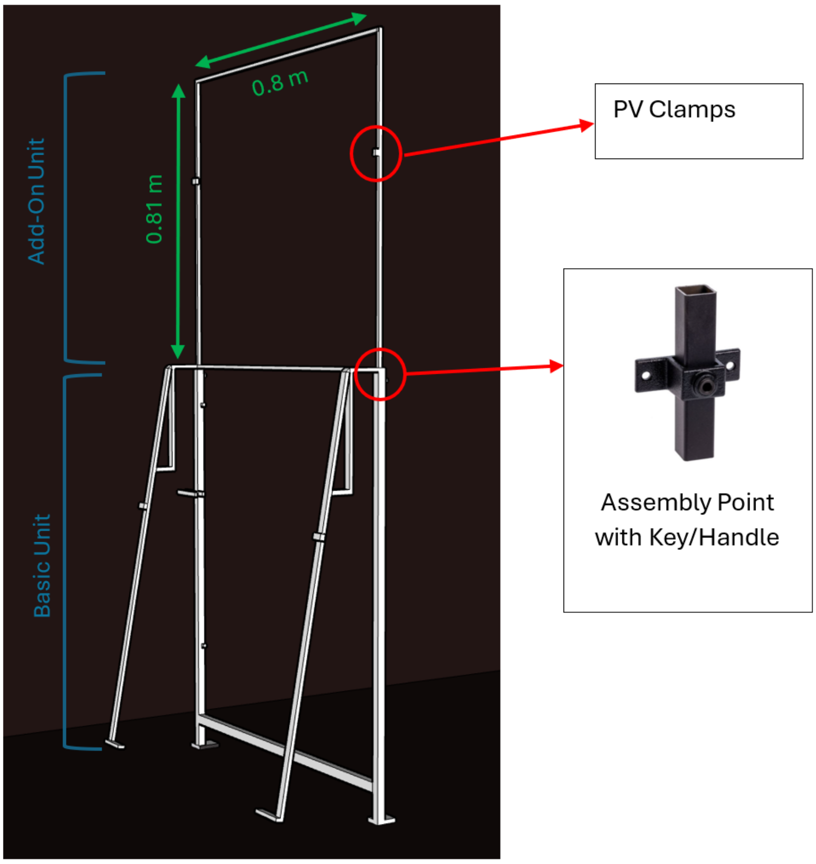


Figure 6.7: Privacy Plan Mounting Structure (Basic and Add-On units)

Now that the design of the structure is finalized, it is crucial to select the material used as this will serve in defining the product costs and specifications. The most common materials used for solar mounting structures are aluminum, galvanized steel, and stainless steel. After consulting an expert in steel manufacturing, he suggested using stainless steel as it possesses high corrosion and rust resistance allowing it to last a long lifetime. However, this material was found to be expensive, adding significantly to the initial cost of the system. Hence, the use of aluminum was considered as this material is easy to manufacture, lightweight, corrosion-resistant, and less expensive than the latter. However, even though this material is cheaper than stainless steel, it is still an expensive option. Since the cost-effectiveness of the business model plays a crucial role in its success, a good alternative was found to be the use of galvanized steel. While this material possesses higher corrosion and rust potential, this can be mitigated by applying a galvanization layer or coating every couple of years. Moreover, as the galvanization layer must be added after welding the attachments to the structure, regular maintenance must take place to ensure the welding spots are coated and galvanized to prevent corrosion and rust. Finally, the galvanized steel material was chosen as the material for the Basic and Add-On unit's mounting structures. This leads to a structure with weight of 8 and 2 kg for the Basic and Add-On units and a lifespan of 75 years under consistent maintenance.

6.2.4. Power Cables

In order to choose the type and length of power cables used in the system, it is essential to draw the system layout assuming that multiple units will be installed on the same balcony.

From the layout in figure 6.11, the following cables and electrical components were identified:

- DC cables to connect the panel to the microinverter.
- AC cables to connect the microinverters between each other.

- One AC Plug-and-Play cable to connect the AC output of the system to the grid socket.
- AC Trunk Cable to connect each microinverter to the other.

The length of cable run considered for these cables is around 1 meter for each of the DC and AC cables, and 2-3 meters for the Plug-and-Play AC cables to account for a grid socket that is distant from the installed system.

6.2.5. Aesthetic Enhancements

End-users are offered numerous aesthetic enhancement options to ensure the system is appealing to install on residential units, among these enhancements are:

- Solar Skins

  These solar skins are thin layers of material with a printed design or painting that are placed on the solar panels to enhance their visual appeal, allowing them to mimic the building and its surroundings as shown in the figure 6.8. These skins partially affect the absorption of the system and usually have a lifespan of 25-30 years.

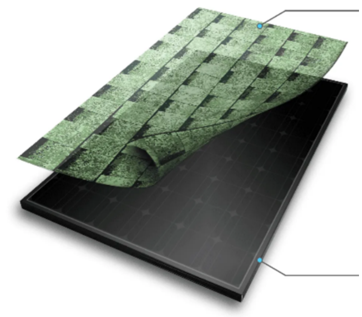


Figure 6.8: Solar Skin [115]

- Artificial Green Screens

  Another enhancement that can be installed on the back of the system (facing the balcony) is artificial vegetation as shown in the figure 6.9. These enhancements add greenery to the balcony, offering the dual purpose of enhancing the design of the balcony while allowing for solar power generation. Usually, artificial climbing vegetation has an expected lifespan of 5 years [22].

Figure 6.9: Artificial Green Screen [142]

- Fabric Sails

The customers have the option to integrate fabric sails instead of green screens if they opt to go for a simpler and more customized appearance on their balcony as shown in figure 6.10. These systems have an approximate lifespan of around 10 years [109].

Figure 6.10: Fabric Sail [121]

- Plant Pots

  Hanging plant pots are also an option as they can be hung on the back of the mounting structure adding vibrant colorful flowers to the balcony. This integration of enhancements helps in seamlessly blending nature and technology.

6.2.6. System Layout and Safety Considerations

In this section, the layout of the system is presented, highlighting the connections between the panels, inverters, cables, and utility grid sockets. Next, safety requirements are presented to ensure the system abides by electrical safety standards.

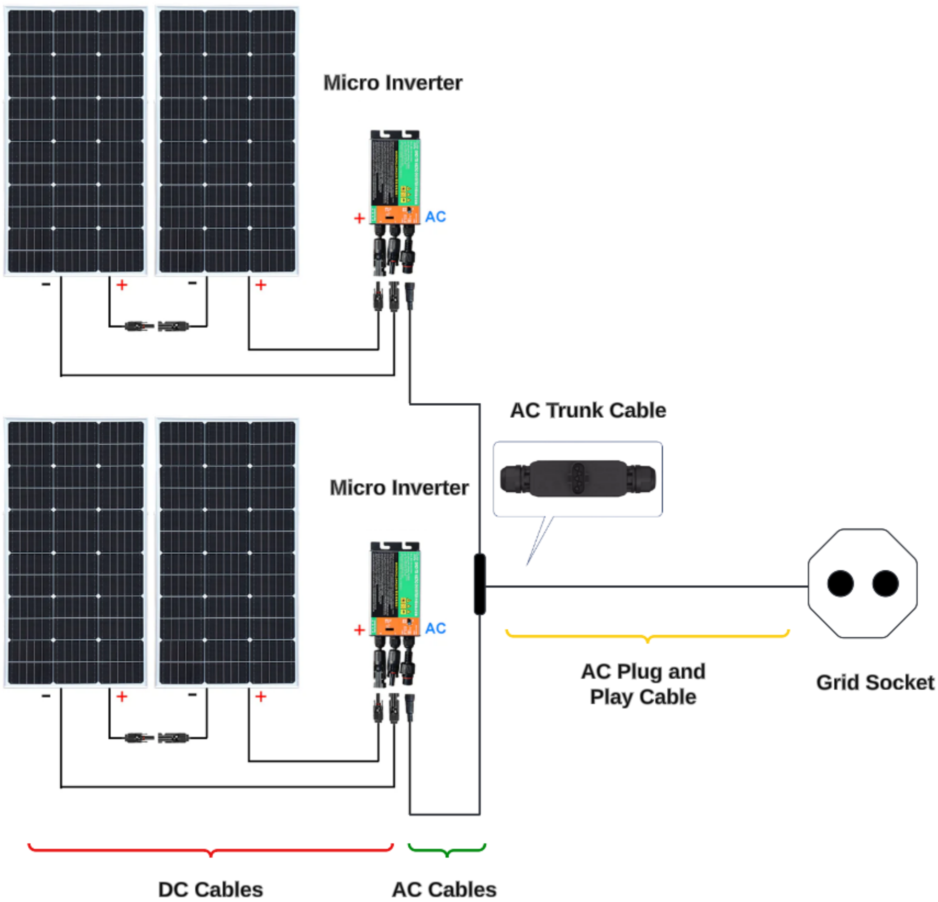


Figure 6.11: System Layout

From figure 6.11, it can be inferred that each solar panel is connected to a second panel in series using DC cables. Next, the positive and negative sides of the cables are connected to a microinverter. Each microinverter transforms the electricity from DC to AC adjusting the voltage and frequency to match the specifications of the utility grid socket. In the case where multiple systems are installed, the microinverters are connected to each other in parallel using AC trunk cables. Finally, an AC Plug-and-Play cable is used to connect the systems to the utility grid socket.

Safety Precautions

From a safety perspective, it is crucial to ensure that the current reaching the grid socket is lower than the maximum allowed current of 16A. To ensure that, the maximum number of microinverters was calculated by dividing the maximum allowed socket current by the rated output current of the inverter as indicated by

$$\text{Maximum number of panels} = \frac{\text{Allowed Maximum Current}}{\text{Current Output per Microinverter}} = \frac{16\text{A}}{1.52\text{A}} = 10.5 \qquad (6.1)$$

This means that a maximum of 10 microinverters can be connected to the same grid socket, which is equivalent to 20 panels.

In addition, the system should be grounded to prevent electrical shocks and reduce the risk of electrical accidents and fuses should be installed to protect against overcurrents. Moreover, the microinverter chosen comes with all-around protection, including anti-island protection in case the electricity grid is down or under maintenance.

To summarize, table 6.1 represents the product specifications of the Basic and Add-On units.

Product Specifications	Basic Unit	Add-On Unit
PV Panel		
Number of Panels	1	1
Type	Monocrystalline (PERC)	Monocrystalline (PERC)
Rated Power [W]	150	120
Efficiency [%]	21	21
Dimensions [L×W×H]	990×766×35 mm	804×766×35 mm
Active Area [m^2]	0.66	0.53
Inclination (vertical)	10°	0°
Weight [kg]	8.3	7.9
Mounting Structure		
Material	Galvanized Steel	Galvanized Steel
Dimensions [L×W×H]	800×150×1000 mm	800×50×810 mm
Weight [kg]	8	2
Inverter		
Type	Microinverter	Microinverter
Number	1 per plan	1 per plan
Rated Power [W]	350	350
Efficiency [%]	95	95
Weight [kg]	1.8	1.8
Wi-Fi Monitoring	Included	Included
MPPT	Included	Included

Table 6.1: Product Specifications for Basic Unit and Add-On Units

6.3. Subscription Type

In combination with the development of the product specifications, it is critical to select a payment method that aligns with the design and business model. From literature, two main pricing methods stand out:

Pay-per-kWh

This model relies on the company pricing the subscription per kWh and the customers paying for each kWh their system is generating. Under this model, the customers pay for the electricity their systems produce on a monthly basis.

Advantages

- Fair Pricing: This model is advantageous for people with a sub-optimal balcony orientation, as the end-users pay for each kWh their system is generating and not for predetermined electricity yield expectations.
- Profit Guarantee: Ensures profit for both the company and the end-users by making sure that both actors are sharing the cost difference between the market price and LCOE of each kWh generated. For example, even if the system of an end-user generates less than expected (but more than the minimum electricity yield specified), both the company and the end-users can make a profit.

Disadvantages

- Complex Revenue Streams Estimations: Complexity in estimating the revenue streams of the company, as each system generates a specific electricity yield, and the total subscription fee will depend on this consumption value.

- Complex Total Subscription Fee Calculation: Complexity in calculating the subscription fee of each customer for a month/year. This is mainly caused by the fact that each customer has an individual electricity yield and hence a specific subscription fee that he must pay at the end of the specified period. Hence, the company should ensure a robust metering and pricing system.

Fixed Subscription

Under this model, the service company sets a fixed subscription fee for each system that the customers can pay at the start or end of each month.

Advantages

- Accurate Revenue Streams Estimations: Since the subscription is fixed and similar for all the customers, it is easier for the service company to estimate its revenue streams.

Disadvantages

- Subscription Fee Uncertainty and Loss Potential: For the company to estimate the fixed fee the customers should pay per unit; it must make estimates of the electricity yield expected by each system. This further adds to the uncertainty of the model, and the customers and companies can end up saving either less or more than expected. For example, if the company estimates a yearly electricity yield and prices according to these expectations, the customers with an electricity yield lower than this estimation can end up paying more than the amount saved.

Knowing the benefits and drawbacks of each type of subscription model, the **Pay-per-kWh pricing scheme** was found to be superior, as it allows for guaranteed cost savings and fairness among all customers without allowing end-users with a more favorable balcony orientation a significant advantage over the other customers. Consequently, under this pricing scheme, end-users pay at the end of each month for each kWh generated by their respective system and recorded by the monitor of the microinverter.

6.4. Cost Structure

The next crucial step involves defining the cost structure for producing the offered product and operating the business model. The cost structure of the business model consists of two categories, the capital expenditure (CAPEX) which refers to the costs of the initial investment, and the operational expenditures (OPEX) representing the day-to-day costs of running the business model. To simplify these calculations, **all costs were considered per plan** [1].

6.4.1. Capital Expenditures (CAPEX)

First, the CAPEX costs of the business model are identified. It is important to note that the lifespan of each component is determined to adjust the time period of each unit and account for replacement costs when needed.

PV Panel

According to the manufacturer, the wholesale price of the solar modules selected is around 0.13€/Wp [118]. Hence, the 150 and 120W panels will cost a total of approximately 19.5 and 15.6€, respectively. As previously mentioned, the Basic plan consists of two 150W panels, and the Privacy plan of one 150W and one 120W. This leads to a total panel cost of 39 and 35.1€ for the Basic and Privacy plans, respectively.

In addition, the panels under the PaaS business model are susceptible to frequent transportation, installation, and removal. Hence, the lifetime of these panels was assumed to be 25 years.

[1] As previously mentioned, the Basic plan consists of two Basic units and the Privacy Plan consists of one Basic unit and one Add-On unit.

Microinverter

The microinverter is considered to have a retail market price of 80€ [131]. However, to consider the wholesale of the product a 50% markup was assumed. Consequently,

$$\text{Wholesale Price} = \text{Retail Price} \times (1 - \text{Markup}) = 80 \times 0.5 = 40\,€ \tag{6.2}$$

Since each plan consists of one microinverter, this results in a total microinverter cost of 40€ for the Basic and Privacy plan, respectively.

These microinverters are assumed to have an average lifespan of 25 years [110] [36].

Mounting Structure

To calculate the expected wholesale cost of the mounting structure of the system, an expert in steel manufacturing was consulted, and the price was assumed to be 100€ for the Basic unit and an additional 20€ for the Add-On unit with an expected lifespan of 75 years. Hence, the total cost of the mounting structure for the Basic and Privacy plans is 200 and 120€, respectively.

Since the lifetime of the system is assumed to be 25 years, a linear depreciation method was used to estimate the salvage value of the system at the end of the period.

Power Cables

The DC and AC cables with a length of 1-meter cost around 1€ each [27]. The Plug-and-Play cable costs around 8€ under wholesale prices. However, as one Plug-and-Play cable is needed for multiple systems (on average 2), the total cost of a Plug-and-Play cable per unit was assumed 4€ per plan. In addition, the AC trunk cable connection was found to have a 10€ wholesale price. However, a total of one AC trunk cable is needed for two plans, meaning that a total of 5€ is needed for each plan.

This leads to a total of around 11€ for the Basic and Privacy plans, respectively.

The lifespan of these cables was assumed to be 25 years [26].

Aesthetic Enhancements

To simplify the cost structure, these enhancements were considered to have the same price and lifespan, with a price of 3€ for the Basic and Privacy Plans.

These enhancements were assumed to have an approximate lifespan of 10 years, meaning they should be replaced every 10 years.

Tax

As the company owns the systems, a VAT tax of 21% of the total product price should be paid.

Replacements

All the components of the system ideally fulfill the lifespan of 25 years, except for the case of aesthetic enhancements which should be replaced every 10 years. These replacement costs were accounted for in the cost structure cash flow.

6.4.2. Operational Expenditures (OPEX)

Next, the operational costs are calculated for the following activities:

Maintenance

The maintenance cost for solar systems accounts for around 2% of the initial system cost [76]. However, the system has a modular design, and users handle seasonal cleaning themselves. Additionally, the system has a durable design that minimizes wear and tear and ensures long-term reliability, which keeps maintenance expenses low. This significantly reduces maintenance costs to around 1% of the initial investment, resulting in 3.5 and 2.1 € for the Basic and Privacy plans, respectively.

The maintenance of this system accounts mainly for the galvanization coating and the cases where the clamps fail. In addition, end-users are expected to lease the products offered by the business model for an average of three years, which means these operational costs occur every three years.

Shipment

Assuming the company offering the service takes responsibility for shipping the products without the need to partner with another shipping company, the shipment calculations indicated in K were made. These preliminary estimations resulted in a shipment cost of 1.4 and 2.1 € for the Basic and Privacy plans, respectively.

In addition, as end-users are expected to lease the products for an average of three years, these operational costs were considered to occur every three years.

Insurance and other Services

These costs cover the price of insurance that the business should pay to ensure that its products are insured in the case of any accident or failure. Furthermore, these costs cover essential services required for the business model to operate, such as solar system design software, website maintenance, customer service, and related expenses. These costs usually contribute to around 2% of the initial cost of the product [64]. However, as previously mentioned, the system offered has a simpler and more modular design compared to rooftop systems, resulting in these costs being reduced to just 1% of the initial investment.

It is worth mentioning that these costs are expected to occur annually. In addition, the system is designed for Do-It-Yourself assembly, however, if customers want the service company to install the system, this results in an additional constant fee to the subscription price.

To summarize, the following table indicating the CAPEX and OPEX costs of the Basic and Privacy plans was deduced, as shown below.

	Basic Plan (€)	**Privacy Plan (€)**	**Lifespan/Frequency**
Solar Panel	39	35.1	25 years
Inverter	40	40	25 years
Cables	11	11	25 years
Mounting Structure	200	120	75 years
Aesthetic Enhancements	3	3	10 years
Tax	61.5	25.1	x
Capital Costs (€)	**354.5**	**209.1**	x
Maintenance	3.5	2.1	Every three years
Shipment/Delivery	1.4	2.1	Every three years
Insurance and Permits	1.8	2.2	Annually

Table 6.2: Cost Structure of Basic and Privacy Plans

To conclude, as shown in table 6.2, the CAPEX of the Basic and Privacy plans are **354.5** and **209.1 €**, respectively. For the OPEX, the sum of maintenance and shipment taking place every three years are **4.9 €** and **4.2€** for Basic and Privacy plans, respectively. In addition, the insurance, permits, and services contribute to a yearly OPEX of **3.5€** and **2.1€** for each of the Basic and Privacy subscriptions.

6.5. Electricity Yield and Levelized Cost of Electricity (LCOE)

Once the cost structure of each subscription over 25 years was determined, the yearly electricity yield of the system over this period was calculated to finally compute the Levelized Cost of Electricity (LCOE) for each subscription plan.

First, the irradiance hitting the 10-degree and vertical panels was computed hourly using Meteonorm in all four orientations (South, East, West, and North). Next, the resulting values were summed over one year to compute the yearly irradiation on the inclined and vertical panels, as indicated by table 6.3.

Orientation	$G_{\text{module, O},i}$ [kWh/m^2 · year]	
	Basic Unit	**Add-On Unit**
South	918	815
East	699	632
West	694	629
North	x	x

Table 6.3: Global irradiation incident on panel surface

Afterward, the irradiation was multiplied by the performance ratio, area, and efficiency of each panel "i". The result was multiplied by the efficiency of the microinverter, cables, and shading of the surroundings to account for electricity losses, as shown in equation 6.3.

$$E_{\text{O},i} = \text{G}_{\text{module, O},i} \cdot n_i \cdot \text{PR} \cdot n_{\text{Inverter}} \cdot n_{\text{Cables}} \cdot \text{(1-SF)} \cdot \text{A}_i \tag{6.3}$$

Where,

- $E_{\text{O},i}$ (kWh/y): Total energy output from unit "i" with orientation "O"
- $G_{\text{module, O},i}$ $(kWh/m^2.y)$: Irradiation on modules of unit "i" with orientation "O"
- n_i: Efficiency of panels (0.21)
- PR : Performance ratio (0.8)
- n_{Inverter} : Efficiency of the microinverter (0.95)
- n_{Cables} : Efficiency of the cables (0.98)
- SF: Shading factor (0.1)
- A$_i$ (m^2) : Active area of unit "i" 6.1
- "i" represents the type of unit: Basic and Add-On.

To account for the shading caused by the surrounding environment a shading factor of 10% was considered. In addition, the panel electricity yield was multiplied by the inverter and cable efficiencies assumed 95 and 98% respectively, resulting in the total electricity yield of each system.

For the sake of simplicity, all balconies were assumed equally likely to be oriented in the three orientations (South, East, and West) and that most balconies have a better orientation than North. In the case where a balcony has a North orientation only, then it is not profitable to subscribe to the service. Hence, the weighted average electricity yield of each system was calculated using the following equation:

$$E_{\text{average, yearly},i} = \frac{1}{3} \times E_{\text{South},i} + \frac{1}{3} \times E_{\text{East},i} + \frac{1}{3} \times E_{\text{West},i} \tag{6.4}$$

The resulting electricity yield for each subscription in the South, East, and North orientations and the weighted electricity yield are presented in table 6.4.

Electricity Yield (kWh/y)	Basic Unit	Add-On Unit
$E_{\text{average},i}$	68.4	49.2
$E_{\text{South},i}$	81.5	57.9
$E_{\text{East},i}$	62.1	44.9
$E_{\text{West},i}$	61.6	44.7

Table 6.4: Electricity Yield of Basic and Privacy Subscriptions

Since the Basic plan consists of two Basic units and the Privacy plan consists of one Basic unit and one Add-On unit, hence the following equations were obtained:

$$E_{\text{O},BasicPlan} = E_{\text{O},BasicUnit} + E_{\text{O},BasicUnit} \tag{6.5}$$

$$E_{\text{O},PrivacyPlan} = E_{\text{O},BasicUnit} + E_{\text{O},Add-OnUnit} \tag{6.6}$$

Hence, the total electricity yield of the Basic and Privacy plan systems is summarized in table 6.5.

Electricity Yield (kWh/y)		
	Basic Plan	**Privacy Plan**
E_{average}	136.8	117.6
E_{South}	163	139.4
E_{East}	124.2	107
E_{West}	123.2	106.3

Table 6.5: Electricity Yield of Basic and Privacy Subscriptions

Over the years, the efficiency and performance of the panel decrease linearly by a factor x, known as the degradation factor. This reduction in electricity yield for each year "t" was accounted for using equation 6.7, where x was estimated to be $0.5\%/year$ [101].

$$E_t = E_{t=0} \times (1 - x \times t) \tag{6.7}$$

Now that the cost structure and average electricity yield for each plan were determined, the LCOE of each subscription was calculated using equation E, as shown in table 6.6.

The assumptions for this calculation are the following:

- *Discount Rate= 5%* [136].
- *Time Period: 25 years.*

The calculations reveal that the LCOE for the Basic and Privacy subscriptions are **0.223** €$/kWh$ and **0.149** €$/kWh$, respectively. It is worth mentioning that the LCOE of the Privacy plan is lower than that of the Basic plan, meaning that the cost of every kWh generated by the Privacy plan is lower than that of the Basic. This means that the Privacy plan subscription is more attractive to the company and end-users compared to the Basic plan subscription. As mentioned at the beginning of the section, the LCOE indicates the cost of generating one kWh taking into account the time value of money. Consequently, this metric enables the comparison of the plans offered by the PaaS business model with the electricity grid and other sources of electricity generation. Comparing these values with the average wholesale electricity price of 0.34€$/kWh$ indicates that both subscriptions cost less per kWh than the electricity grid.

	Basic Plan	Privacy Plan
LCOE (€$/kWh$)	0.223	0.149

Table 6.6: LCOE of Basic and Privacy Plans

To conclude, the weighted electricity yield for the Basic and Privacy subscriptions are **137** and **118 kWh/y.plan**, respectively. This calculation helped determine the LCOE of each subscription using the cost structure defined in section 6.4. The results demonstrate that the cost of electricity generated by these plans is lower than that of the Dutch electricity grid. This means that a profit margin exists for the company and the end-users to profit from and also underscores the economic viability of the business model.

6.6. Pricing Scheme Model

After determining the LCOE for each plan, a pricing scheme model was constructed as shown in figure 6.12. These models take as inputs the subscription type, average market price, the profit factor of the company adopting the business model, the age of the panel, and return the subscription pricing fee, cost savings, and profit estimates either in kWh or yearly, as indicated by figure 6.12.

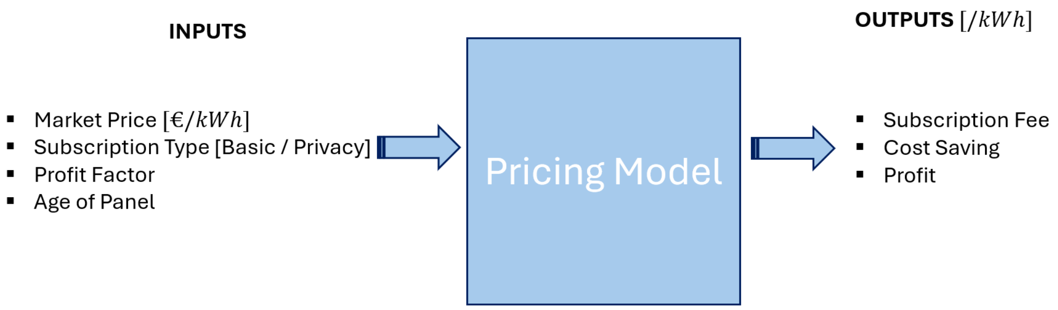


Figure 6.12: Pricing Model

The Pricing Scheme Model consists of two sub-models: the unadjusted pricing model and the efficiency-adjusted pricing model as presented by figures 6.13 and 6.15. This pricing model works as follows. First, knowing the subscription type helps determine the LCOE of the selected plan that was calculated in section 6.4. Next, this LCOE value is subtracted from the input average market price (MP) resulting in the cost-saving difference the company makes by installing the system (named A in the Figure). Consequently, the profit factor (PF) determined by the company is multiplied by this difference (A) to account for the profit the company will make for each kWh produced by the system. To calculate the subscription fee per kWh, end-users must pay for the LCOE of the system (€/kWh) in addition to the unadjusted profit (Pu) the company wants to make, resulting in $PM * A + LCOE$. The cost savings end-users are making on every kWh is the pricing per kWh they are paying (B) subtracted from the market price they should be paying in case they are not subscribed for the system resulting in $C = MP - B$ for every kWh.

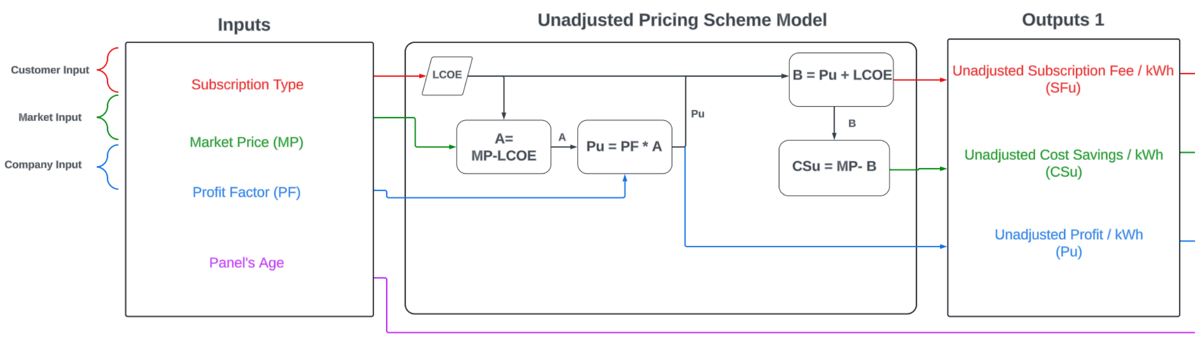


Figure 6.13: Unadjusted Pricing Model

It is important to note that as the panel ages, its efficiency is reduced by the degradation factor x. So, if a customer is using a panel that is "t" years old, his system will end up generating less electricity than a panel at time t=0. Consequently, the company offering the service will have to compensate for this difference by using the **Efficiency Adjustment Model**, indicated by figure 6.15. This model takes as input the age of the panel, the unadjusted subscription fee (SFu), cost savings (CSu), and profit (Pu) per kWh. This model ensures that end-users are compensated for the electricity yield that is not generated by their system because of the panel's degradation. Knowing the age of the panel determines the electricity yield that was supposed to be generated by the panel at year "t=0" using equation 6.7.

To compensate for end-users, the total cost savings at year t should be equal to the total cost savings assuming the panel is brand new at "t=0". Hence,

$$\text{Total Cost Savings}_t = \text{Total Cost Savings}_0 \tag{6.8}$$

$$E_t \times CS_a = E_0 \times CS_u \tag{6.9}$$

$$E_0 \times (1 - x \times t) \times CS_a = E_0 \times CS_u \tag{6.10}$$

$$CS_a = \frac{CS_u}{(1 - x \times t)} \tag{6.11}$$

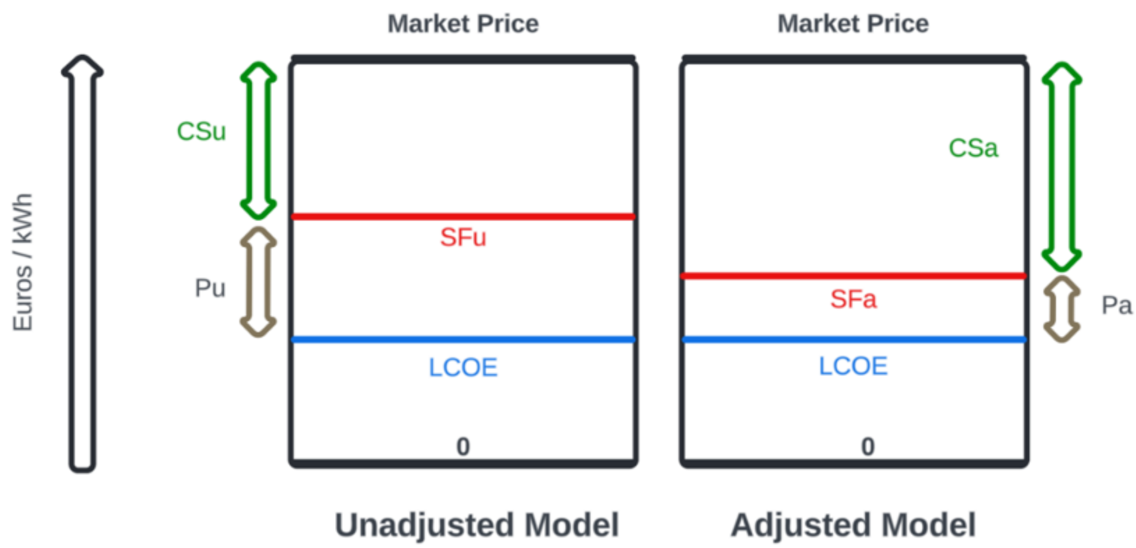


Figure 6.14: Pricing Structure

Consequently, CS_a represents the adjusted cost saving per kWh taking into consideration the degradation of the panel x at age t.

Subsequently, according to figure 6.14, the adjusted subscription fee the company is making on each kWh is the adjusted cost savings CS_a subtracted from the market price of electricity:

$$SF_a = \text{Market Price} - CS_a \tag{6.12}$$

In addition, the adjusted subscription fee the company is making on each kWh is the levelized cost of electricity subtracted from the adjusted cost savings CS_a:

$$P_a = CS_a - LCOE \tag{6.13}$$

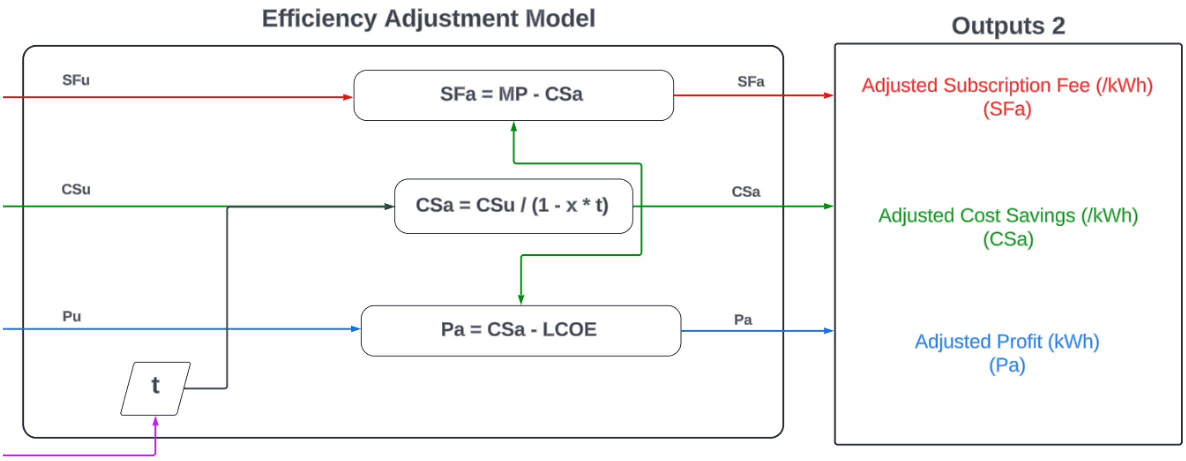


Figure 6.15: Efficiency Adjustment Model

Once the adjusted subscription fee, cost savings, and estimated profit are computed for each kWh generated, an optional final model is used to compute these values yearly based on actual or estimated electricity generation E_y or E_t for a year t. The values E_y and E_t representing the estimated and actual electricity yield are then multiplied by output 2 to return the yearly estimated/actual subscription fee, cost savings, and profits.

This pricing scheme model will be used in chapter 7 to compute the financial metrics from the perspective of the company and end-users.

6.7. Contract Specifications

In the development of a business model, it is important to focus on clearly outlining the contract specifications. This section outlines the essential terms for end-users to abide by when subscribing to the business model.

- Minimum Contract Period: The contract has a minimum of 2-year duration, since contracts with shorter periods cause higher shipment and operational costs, therefore, minimizing the profitability of the business model.
- Billing Cycles: The end-users pay at the end of each month based on the electricity yield recorded by the microinverters.
- Second-hand Panels: Under this business model, most end-users will end up using second-hand panels with reduced performance. For this reason, the company will compensate these end-users by subtracting the difference between the expected electricity yield (t=0) and the actual energy yield of the system using the efficiency adjustment model.
- Contract Cancellation: End users can cancel their contracts at any time at the expense of paying for the electricity their system generated and the shipment fee the company paid to deliver the product. This ensures that the business model is flexible, and customers have the right to cancel their commitment for a minimal fee in case the service does not meet their expectations.
- Loyalty Programs: If the customer subscribes to a contract for more than two years, their cost savings get increased by reducing the profit factor employed by the company by 1%. This offers the incentive for the subscribers to opt for longer contracts.
- Inclusive Maintenance: End-users are offered inclusive maintenance throughout the contract period in case of any failure or malfunction in the system.
- Penalty: End-users will have to pay a penalty fee if their system fails to meet the minimum yield identified in 7.3 because the panel was turned off or placed in a location where it cannot catch sunlight.

7 Financial Assessment

After finalizing the pricing scheme of the business model, and calculating the levelized cost of electricity (LCOE), the financial viability of the business model for both plans was assessed. First, the plans were assessed from the perspective of the company adopting them by focusing on the net present value, internal rate of return, and payback periods, as shown in section 7.1. Next, the analysis was made from the point of view of the end-users subscribing for the business model by estimating the cost savings of each plan and the value these actors are getting in return for the money they are paying, as indicated by section 7.2.

7.1. Company Perspective

To evaluate the profitability of the business model, the net cash flow was computed using equation 7.1. The revenue cash flow was calculated by multiplying the adjusted subscription fee (SFa) computed in section 6.6 by the weighted electricity yield accounting for the degradation of the panel.

$$\text{Net Cash flow}_i = \text{Revenue Cash flow}_i - \text{Cost Structure}_i \tag{7.1}$$

Where "i" indicates the type of subscription fee selected by the end-users (Basic or Privacy subscription).

Once the net cash flows of the two subscription options were figured, the Net Present Value (NPV) and Internal Rate of Return (IRR) values were calculated. Next, the cumulative and discounted cumulative cash flows were calculated to determine the payback period and discounted payback periods.

These metrics were computed based on the assumptions:

1. *Discount Rate = 5%.*
2. *Profit Factor = 25%.*
3. *Time Period = 25 years.*
4. *Market Price = 0.34 €/kWh [89]*
5. *All PV panels and systems were introduced to the market at the same period ($t = 0$).*

Based on the assumptions stated above, the results of the financial metrics employed were found as summarized in table 7.1.

Financial Metric\Subscription	Basic Plan	Privacy Plan
NPV (€/*Plan*)	42.4	59.6
IRR (%)	6.2	7.6
Payback Period (Years)	12.9	11.4
Discounted Payback Period (Years)	21.9	17.9

Table 7.1: Financial Outcomes: Company Perspective

The results show that both subscriptions have an NPV>0, meaning that the cash inflows of each subscription cover the initial investment when accounting for the time value of money.

Additionally, the internal rate of return values are 6.2% and 7.6% respectively. This metric is benchmarked by comparing it to the Weighted Average Cost of Capital (WACC). According to the IEA (2021), the WACC estimates for European solar projects range between 3 to 6%, meaning that the IRR of the Basic and Privacy plans are in the range of the WACC benchmark [16]. Hence, both subscriptions are attractive to companies as they represent an IRR> Benchmarked WACC. It is important to note that these benchmarks are just an estimate to highlight the project's attractiveness, as they are susceptible to change based on each company's goals.

Moving to the payback period, which indicates the time needed to recover the initial investment through cash inflows generated by the revenue subscriptions. The benchmark of a balcony solar project is usually around 6 to 10 years. The results indicated values of 12.9 and 11.4 years for the Basic and Privacy plans, respectively. Comparing these values with the benchmark of a balcony solar project with a payback period ranging between 6 to 10 years, both models indicate a higher value. This is mainly due to the higher operational costs of the PaaS business model and the additional savings going to the company to generate profit. Taking the time value of money into account, the discounted payback period was calculated to be 21.9 and 17.9 years respectively for each subscription. Even though the payback period results are relatively long, the values are within an acceptable range compared to solar energy projects.

Comparing both subscription plans indicates that the company is more interested in customers subscribing to the Privacy plan, as this plan indicates more promising financial results. In addition, the time it takes to cover the cost of initial investment under the Privacy plan is substantially lower than that of the discounted payback period either with or without accounting for the time value of money. This is mainly caused by the higher LCOE value of the Basic plan compared to that of the Privacy plan.

To better present the findings, multiple scenarios of revenue streams were considered. These scenarios estimate the total number of subscriptions the company is expected to offer based on the total number of rental apartments in the country. In fact, according to CBS (2020), there exist 3.3 million rented houses in the Netherlands [126]. As mentioned in chapter 4, 53% of these houses are apartments, leading to a total of 1,750,000 rental apartments. It is important to note that only a percentage of these apartments were considered to subscribe to the business model, as indicated in figure 7.2 and 7.3. Next, each end-user was assumed to subscribe to either two Basic or Privacy plans, as the latter is larger and harder to integrate on a regular balcony.

The results of the estimated revenue streams are indicated in the tables below:

Percentage of Target Segment	Number of Subscriptions (Thousand)	NPV (Million €)
1%	35	1.4
3%	105	4.4
5%	175	7.4
7%	245	10.3
10%	350	14.1

Table 7.2: Revenue Streams Estimates for Basic Plan

End-Users Percentage	Number of Subscriptions (Thousand)	NPV (Million €)
1%	34.9	2.1
3%	104.9	6.2
5%	174.9	10.4
7%	244.8	14.6
10%	349.8	20.8

Table 7.3: Revenue Streams Estimates for Privacy Plan

As shown in table 7.2, if 1% of the target segment subscribes, then an NPV of around 2 million euros is obtained. Under favorable conditions, where around 10% of all rental properties apply for two Basic plans each, the NPV can reach a 20.5 million euro value. On the other hand, table 7.2 indicates that if 1% of the target segment subscribes to the Privacy plan, then an NPV of around 2.6 million euros is obtained. Under favorable conditions, where around 10% of all rental properties apply for three basic models each, the NPV can reach 26 million euro value.

Evaluating the profitability of the business model from the company's point of view is not enough to establish the financial viability of the business model. The participation and satisfaction of end-users with the business model are key to ensuring its profitability. Hence, the cost-effectiveness of the business model was also evaluated from the perspective of end-users in the following section.

7.2. End-user Perspective

As previously mentioned, end-users are key actors in the success of the business model. To test the attractiveness of this business model from the point of view of end-users, two main metrics were studied: The cost savings received and the benefits these customers get in return for the subscription paid.

The main metric used to represent the attractiveness of the business model for end-users is the cost-saving potential. Consequently, the yearly cost savings were computed for each customer when subscribing to one plan of the business model. To calculate these yearly cost savings per plan, the previously computed cost saving/kWh (CSa) computed in section 6.6 for each model was multiplied by the degrading weighted electricity yield. These values were found to be around 12 and 17 €/year for each of the Basic and Privacy plans, respectively. This indicates that for customers with enough space who are willing to install a privacy screen, the Privacy subscription can be optimal, as it allows for additional cost savings compared to the Basic subscription plan.

Subscription	Basic Plan	Privacy Plan
Cost Savings (€/*year.plan*)	12	17

Table 7.4: Cost Savings: End-user Perspective

In addition, these savings represent the subscription for one plan only, meaning that if end-users subscribe to four Basic plans, their cost savings can reach around 48.2€/year, as shown in figure 7.1. On the other hand, for a maximum of four Privacy plans, the total cost savings can reach around 67.9€/year.

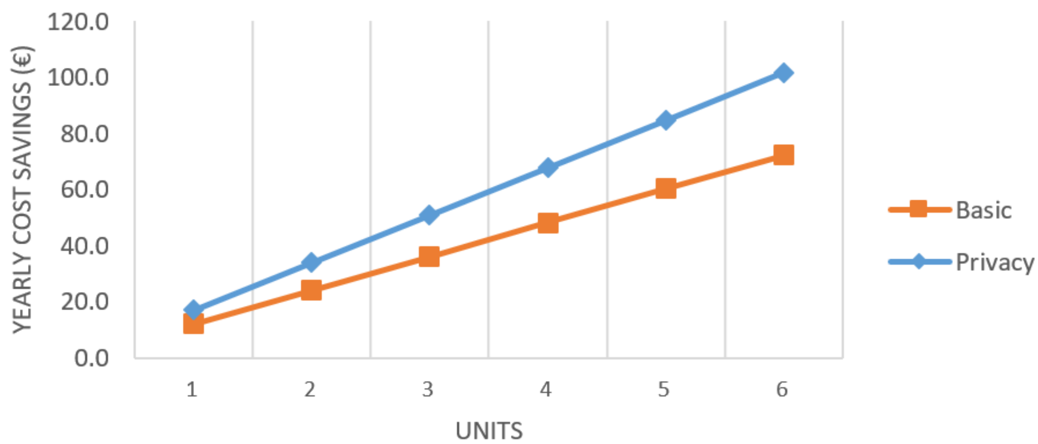


Figure 7.1: Cost Savings per Basic and Privacy Plans

It is important to note that the amount saved is not the only factor that grants this business model its value. Another factor that comes into play is the value received in return for the subscription paid. In fact, the end-users are not only generating revenue that exceeds the subscription fee, but they are also getting the opportunity to install an aesthetic system on their balcony with different customizable options. In addition, end-users subscribing to the Privacy plan get the chance to install a privacy screen allowing for a multipurpose product, offering privacy, aesthetics, green electricity generation, and cost savings at once.

7.3. Sensitivity Analysis

The financial outcomes of the metrics employed to reflect the attractiveness of the business from the company's and end-users' points of view are based on multiple input assumptions. These input assumptions are susceptible to change and could significantly affect the financial outcomes of the business model. Hence, to test the sensitivity of these outcomes to changing assumptions, a sensitivity analysis was conducted to ensure that the most probable scenarios are accounted for. The inputs that were varied in this analysis are the profit factor, market price, discount rate, and system electricity yield.

Market Price

The graphs in appendix L indicate that at a market price below 0.223 €/kWh the IRR and NPV reach a negative value, meaning that below this market price, the Basic subscription is no longer profitable for the company adopting it. Between 0.22 and 0.4 €/kWh (the cap set by the government), the company makes a profit with an IRR ranging between 5.5 and 6.7%, which part it overlaps with the benchmark of 3 to 6%, as previously discussed. In addition, for the maximum market price of 0.4 €/kWh, the NPV reaches a value of 64 €, indicating an attractive business model for the company.

In the case of the Privacy subscription, there is more room for change in terms of market price, as the market price should fall below the LCOE of 0.149 €/kWh for the business model to become unprofitable. On the other hand, for a maximum price of 0.4 €/kWh, the NPV and IRR reach a maximum value of 78 €/plan and 8.4%, respectively. Under the same conditions, the payback and discounted payback period fall to around 10.5 and 15.7 years, respectively.

From the point of view of end-users, if the market price is set a 0.4€/kWh, the cost savings end-users make on each kWh are maximized at 18.2 and 22.2 €/kWh, for the Basic and Privacy plans, respectively.

This indicates that the higher the market price the more attractive the business model for both the company and the end-users. In the case where the market price falls below the LCOE, then the business model becomes unprofitable.

Discount Rate

Varying the discount rate for the Basic subscription plan indicates that beyond a discount rate of around 11%, the IRR and NPV reach a negative value, as portrayed by appendix L. This indicates that above this discount rate, the Basic subscription plan is no longer considered profitable. On the other hand, the lower the discount rate the more profitable the business model for the company.

From the point of view of end-users, the cost savings are maximized when the discount rate decreases. For example, in the case where the discount rate is decreased to 3%, the cost savings for the Basic and Privacy subscription reaches 16.1 and 19.3 €/year.plan compared to 12 and 17 €/year.plan, under previous assumptions.

Profit Factor

As the profit factor increases, the profit of each kWh generated by the system is increased. Hence, as observed in appendix L, the NPV and IRR of the Basic Model can reach around 160 €/plan and 9.2% under 80% profit factor. Moreover, the payback and discounted payback period attain values of 9 and 13 years respectively for a profit margin of 80%. On the other hand, for a profit margin lower than 11%, the business model is no longer profitable as the NPV reaches a negative value.

In the case of the Privacy subscription, the business minimum profit factor that the company can set is around 11%, as below this factor the subscription plan is no longer profitable. However, in the case where the company increases the profit factor to around 80%, the NPV and IRR increase to reach values of 225 €/plan and 14.2%. For the same profit factor, the payback and discounted payback periods are also reduced to reach 7 and 8 years.

From the point of view of end-users, the lower the profit factor the higher the cost savings. In fact, if the profit is reduced to 20%, the cost savings on the Basic and Privacy plans increase to reach 13 and 18 €/year.plan, respectively.

Electricity Yield

During the assessment of the potential location, it is crucial to determine the minimum electricity yield that can be generated while keeping the business model profitable. For the case of the Basic subscription plan, the minimum allowed electricity yield is 90 kWh/year.plan, as below this yield the NPV and IRR reach a negative value, making the business model unprofitable. However, under optimal conditions, the Basic plan can generate around 200 kWh, indicating an NPV and IRR of 99 €/plan and 7.7%. Under this optimal electricity yield, the payback and discounted payback periods attain a value of 11 and 16 years, respectively.

For the case of the Privacy subscription plan, the minimum allowed electricity yield is 60 kWh/year. However, under optimal conditions, the plan can generate around 180 kWh, indicating an NPV and IRR of 115 €/plan and 10%. Under this optimal electricity yield, the payback and discounted payback periods attain a value of 8 and 12 years, respectively.

From the point of view of end-users, if the electricity yield generated by Basic and Privacy plans is lower than around 45 and 60 kWh/year.plan respectively, there are no cost savings for the end-users. On the other hand, the higher the electricity yield, the more savings the end-users make. For example, under optimal operating conditions, each of the Basic and Privacy plans can save end-users a total of 28 and 33 €/year.plan, respectively.

To conclude, the financial viability of the business model was studied from the company's and end-user's perspective. From the point of view of the company, the net present value, internal rate of return, payback, and discounted payback periods were calculated. The business model turned out to be financially profitable with an NPV of **42.4 and 59.6 €/plan** and an IRR of **6.2 and 7.6 %**, for the Basic and Privacy plans, respectively. From the perspective of end-users, the cost savings of the Basic and Privacy subscriptions were evaluated and found to be **12 and 17 €/year.plan**, respectively. This indicates that both plans are cost-effective and profitable to end-users by reducing their electricity bills. In addition, the business model provided additional benefits such as aesthetics and privacy, allowing customers to enhance their balcony space. An important observation is that the Privacy plan is more attractive to companies and end-users as it generates high returns and cost-savings. However, the system offered by the Privacy plan doesn't fit all types of balconies, meaning that the subscription to this plan can be feasible for only part of the target segments. Consequently, offering both plans allows the company to adopt the business model to cover a broader market share. Finally, a sensitivity analysis was performed to study the change in financial metrics and outcomes as the inputs and assumptions are varied. The findings indicate that the higher the market price the higher the profit to the company and end-users. In addition, below an electricity yield of 50 and 60 kWh/year.plan for the Basic and Privacy plans, the end-users will not make any cost savings, making the business model unattractive. Moreover, below a profit factor of 11%, the company can no longer cover its initial costs, making the business model unprofitable.

8
Market Evaluation

Upon developing the business model, it is essential to collect feedback from end-users to understand and identify their concerns. Identifying these concerns highlights areas in the business model that should be improved to ensure the model meets the target group's expectations. Consequently, companies can rely on this feedback to refine the business model by further ameliorating its product design and service offerings, therefore maximizing its attractiveness to target groups and other customers.

To gather feedback, interviews were conducted with five potential end-users, where three of them were already interviewed for the consumer behavior chapter, in addition to two new members who also belong to the target segment selected. Interviews were considered as they allowed to effectively describe the business model and convey the feedback and suggestions qualitatively while leaving room for the exchange of ideas and discussions. The interviews consisted of giving a detailed description of the products offered, the pricing scheme, subscription plans, contract specifications, and other information about the business model. Next, the interviewees were asked to provide feedback, concerns, and considerations that they perceived as ambiguous or missing, or even improvement features that can be added to ameliorate the business model. Some of the improvement features and suggestions were reintegrated into the final concept and the ones that were not applicable are stated in the recommendations chapter 10.

After presenting the business model specifications, end-users were asked to provide their interest in subscribing to one of the offered subscriptions. In fact, all the interviewees demonstrated their enthusiasm, as they considered the model to address a challenge by offering an opportunity for an untapped target segment to gain access to PV systems. Aside from generating clean electricity and reducing their electricity bills, participants were interested in subscribing to this business model for its ability to aesthetically enhance their balcony spaces and offer privacy screen features. Hence, all interviewed potential customers expressed their interest in subscribing to one of the plans in the case of a future market launch.

Next, the interviewed potential customers were asked to highlight the concerns and improvement points of the business model.

First, some end-users were concerned about the complexity and ambiguity of the pricing scheme employed which raised suspicion in the subscription calculations. In addition, some participants mentioned potential budgeting issues resulting from the unpredictable monthly subscription fees caused by the variable electricity yield of the system. Interviewees also questioned the frequency of the electricity market price update, as the wholesale electricity price is uncertain and fluctuating. End-users also had concerns about the low-cost saving potential of subscribing to the business model, especially for the Basic subscription plan.

Concerning the system design and installation, some end-users who do not possess experience and knowledge of electrical devices and components were concerned about the safety of installing an electrical device without the help of an expert as this can result in dangerous accidents. Aside from that, several interviewees mentioned that the low capacity and smaller system dimensions of the system can increase the time needed to install all the systems which makes the process time-consuming. As mentioned in the product specifications, for tenants not willing/able to install the system themselves, a technical expert can be assigned to install the system when shipped in return for an additional fixed subscription fee. One of the interviewed tenants indicated that this fee is a “hidden cost” that can affect the cost-saving estimates promised to the end users. One participant was concerned about the potential noise issues caused by the bumping of the mounting structures on the railing under gusty wind conditions. Other concerns were related to the compatibility of the basic mounting structure to glass balcony railings or ones with curved and unusual railing designs.

From a legal and regulatory perspective, questions were raised around the acquisition of permits from the members of homeowners’ associations as the system is considered to cause changes to the exterior of the building. Moreover, as the net metering scheme is to be ended in 2027, end-users were worried about the consequence of the absence of net metering on the cost-saving estimates. Aside from that, for privately owned properties, the landlord is responsible for paying the electricity bill. This presented concerns about the involvement of the landlord in the process and the complexity of managing the bills and coordinating to receive savings.

All these concerns and insights were essential in shedding light on the main points the end-users look for when subscribing to a balcony PV system under the PaaS business model. Based on the feedback obtained, the following changes were implemented to the PaaS business model:

- The noise caused by the bumping of the mounting structure on the railing was solved by adding durable rubber attachments at the point of contact between the mounting structure and the railing.
- The installation service fee was not made inclusive, however, was offered at a competitive price to give access to end-users who are not able to install the system themselves while incentivizing others to rely on the DIY assembly.
- The basic plan was changed to offer two basic units instead of one to increase its cost-effectiveness, making it more attractive for end-users to subscribe to.

On the other hand, some concerns arising from the nature of the product or specific to the launch phase were not found applicable in the case of this project. These issues are further discussed in chapter 10.

9

Environmental and Circularity Assessment

One of the main advantages of the PaaS business model is its alignment with the principles of circular economy as previously discussed in the literature review chapter. In this chapter, the PaaS business model for balcony PV systems is tested for circularity and sustainability by first explaining the effect of life extension business strategies on material footprint and next by computing its carbon footprint and energy payback period.

9.1. Circularity and material footprint

For a business model to be circular, it must satisfy the key principles of the circular economy framework. The key principle to focus on in this project is the extension of the product's lifetime to minimize its material footprint. To better understand the strategies and processes that support this principle, the three strategies of the 9R framework introduced in the literature review were utilized.

All previously mentioned product life extension strategies are important in reducing the material footprint of solar PV systems. For example, when the components of the product are served to reach their end of life, service providers can refurbish and reuse them to eliminate the need for new components which in turn minimizes waste.

In addition, ensuring regular and professional maintenance makes sure that components' full potential is used, further minimizing the need for replacement. Moreover, the investment in a durable and robust system significantly boosts the lifetime of the system and reduces the operational costs imposed by the system.

Aside from extending the lifetime of the system, the PaaS business model encourages shared usage of products among multiple customers. This means that fewer systems will have to be manufactured to satisfy the demand. In other words, instead of each tenant having to install his own balcony PV system, they can share the product which can help satisfy their needs for the specified period without pushing them to commit to long-term systems/products. It is worth noting that this can lead to overproduction and systems not being used as tenants have shorter contracts than the lifespan of PV panels. This pushes tenants to sell their systems, however, this can be challenging as the PV panel is degraded and can no longer generate the intended yield, making it unattractive to other end-users. In this case, the system either goes to waste or is kept in storage without use.

Finally, as mentioned in the circular economy section, having the service providers take responsibility for the recycling of products can be more efficient than leaving the choice to the customers as they do not have the incentive nor the access to efficient recycling programs which results in increased waste and raw material extraction.

9.2. Carbon Footprint and Energy Payback

To compete with fossil fuels, the business model considered necessitates two key characteristics. First, the greenhouse gases emitted to produce the system and maintain its functioning over its lifecycle should be substantially lower than the emissions of the electricity grid in the country. Secondly, the energy required to produce the system and ensure the operation of the business model over its lifetime should be lower than the energy produced by the system over its lifetime. To assess the satisfactoriness of these conditions, the carbon footprint and energy payback time for the system were computed in this section.

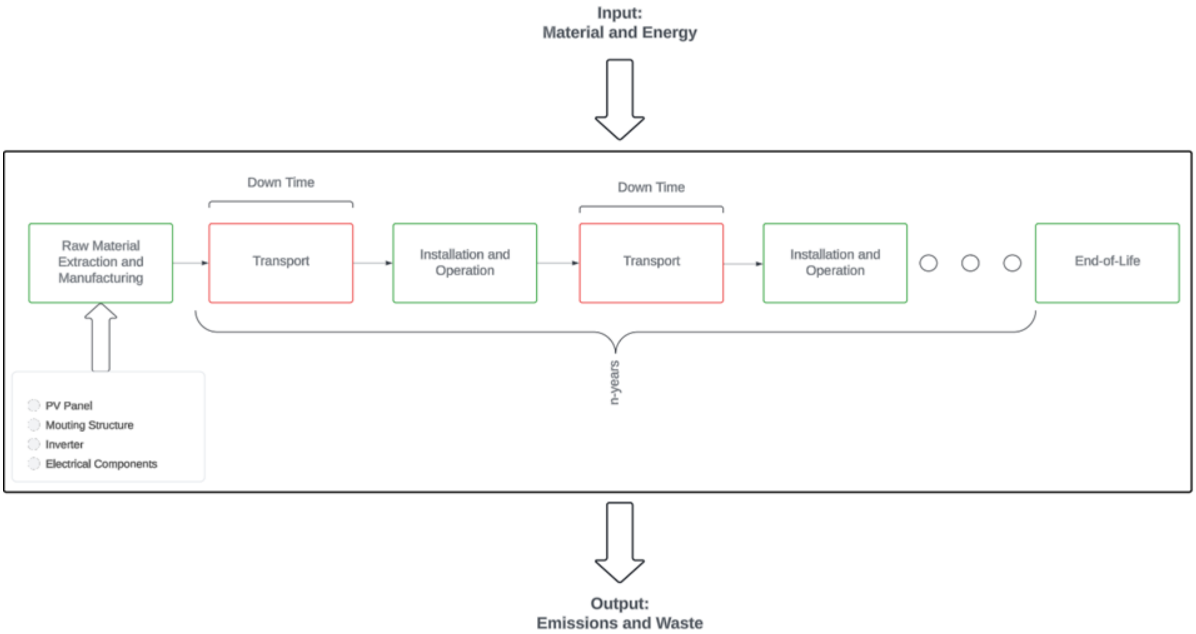


Figure 9.1: Caption describing the picture

Before computing these metrics, it is important to understand the life cycle of the PV system under study. The life cycle starts with extracting the materials that will produce the system. Next, the system is manufactured to obtain the components that will form the system. Afterward, the product is transported from the warehouse of the company or the manufacturer to the end-users, where the system is installed and put into operation. In the use phase, maintenance is carried out every year to ensure the functioning of the system throughout its life cycle. Finally, after the system reaches its lifetime, it reaches the end-of-life phase, where it is either repurposed, recycled, or discarded. In this analysis, the most crucial stages are considered: Manufacturing raw materials extraction, transport, and maintenance as these are the main hotspots of carbon emissions in this business model (indicated in Red in the figure below). The end-of-life and installation emissions were ignored in this analysis (indicated in Green). It is important to note, that because of the nature of the PaaS business model, the operation/installation and the transport processes are repeated every couple of years throughout the lifetime of the system to indicate that the system was transferred to another customer.

9.2.1. Energy Payback Time

While PV systems generate electricity, their manufacturing and production, as well as the processes needed to sustain the operation of the business model such as transport and maintenance, also consume energy known as embodied energy. Consequently, to assess whether this system is capable of generating more energy than the one required to produce it, the energy payback period of the business model was computed using equation 9.1. This equation calculates the time it takes for the system to recover the amount of energy spent to produce the product served and the operation of the business model. It is worth mentioning that the energy of disposal of the panel/system was ignored.

$$\text{Energy Payback Time (EPBT)} = \frac{E_{\text{PV Panel}} + E_{\text{Mounting Structure}} + E_{\text{Inverter and Cables}}}{(E_{\text{Basic, Privacy}}/\eta_G) - E_{\text{Transport}} - E_{\text{O\&M}}} \quad (9.1)$$

Where,

- $E_{PVPanel}$, $E_{MountingStructure}$, $E_{Inverter,Cables}$ indicate the energy consumed to produce the PV panels, mounting structure, inverters, and cables covering raw material extraction and manufacturing.
- $E_{Basic,Privacy}$ represents the actual electricity generated by the system for each of the two subscription plans.
- $_g$ the grid efficiency (assumed 0.31).
- $E_{Transport}$, $E_{O\&M}$ represent the yearly operational energy for transport, maintenance, and operation of the products offered.

The embodied energy of the business model consists mainly of the following products and processes:

Raw Material Extraction and Manufacturing

To perform this analysis, numerous life cycle assessments (LCAs) of PV panels were used.

PV Panel

According to Tanveer et. al. (2022), $1.6 * 10^7 kWh$ is needed to produce $5MWp$ of solar panels. This means that one panel with an efficiency of 21% and an area of one square meter requires around $547kWh/m^2$. Consequently, the panels for the Basic and Add-On [1] units require respectively **415 and 337 kWh** to be produced [71].

Mounting Structure

According to Tanveer et. al. (2022), the mounting structure requires approximately 25% of the energy required to produce a solar panel. Hence, assuming that the solar panel requires $547kWh/m^2$, equivalent to 383 kWh for the Basic unit, then the mounting structures need 96 kWh to produce. As the Add-On unit consists of a smaller and lighter support structure that has 20% the weight of the basic unit mounting structure, the total energy used to produce this unit equals 19 kWh. Additionally, considering 20% and 10% (for Basic and Add-On units) for the attachments of the mounting structure results in a total of 115 and 21 kWh, respectively. Additionally, it is important to note that under consistent maintenance, this mounting structure can last around 75 years. Hence, assuming that the lifetime of the PV panel is 25 years, this reduces the energy required to produce the structure to **38 and 7 kWh** per unit for the Basic and Add-On units, respectively. These values were found to be similar when compared to other sources [145], where an energy of 34 - 41 kWh per unit was found, further justifying that the values found are within the expected range.

Inverter and Cables

According to I. Nawaz et. al. (2006), the inverter and cables require around $33kWh/m^2$. However, as this source dates to 2006, the energy required has been reduced by 20% to account for newer and more efficient machinery. This means that for the Basic and Add-On units, the total energy required to produce these components is **9 kWh** per unit, respectively. This is because each plan consists of two units and has one inverter, meaning that a total of one inverter is needed per plan. This leads to a total of 18 kWh of energy required for producing each of the Basic and Privacy plan's inverters.

[1] Add-On represents the additional part of the Privacy Plan.

Transportation

Based on the shipment estimations in appendix K, the lightweight vehicles were found to travel around 32 km to deliver 32 units to their respective customers. Assuming the vehicles rely on fossil fuels (mostly gasoline with an energy density of 12.7 kWh/kg) and have a mileage of around 40 kg/100 km. Hence, to travel 32 km the vehicle requires 162 kWh of energy for each round trip. Since the capacity is 32 units (for Basic and Add-On units), this results in around 5 kWh to transport the unit of one plan per round trip. As the system is assumed to last around 3 years on the balcony of the same end-user before it is transported back, the previous value is divided by three, resulting in a total of **1.7 kWh/year** for each of the Basic and Add-On units. Since each plan consists of two units, this leads to a total of 10 kWh/plan for both the Basic and Privacy plans.

Maintenance

As the system does not require significant maintenance, the total energy required was assumed to be equal to 2% of the energy required to produce each of the Basic and Add-On units. This results in approximately 10 and 4 kWh (Basic/Add-On) of the energy required to produce the system for 25 years, which is equivalent to **0.4 and 0.15 kWh/year** for each of the Basic and Add-On subscription plans. Since each plan consists of two units, this leads to a total of 0.8 and 0.55 kWh/year.plan for both the Basic and Privacy plans.

The values were summarized in tables 9.1 and 9.2.

	Basic Unit	**Add-On Unit**	**Basic Plan**	**Privacy Plan**
$E_{PVPanel}$ [kWh]	415	337	830	752
$E_{MountingStructure}$ [kWh]	38	7	76	45
$E_{Inverter,Cables}$ [kWh]	9	9	18	18
Total Fixed Energy [kWh]	471	362	942	833

Table 9.1: Fixed Embodied Energy

	Basic Unit	**Add-On Unit**	**Basic Plan**	**Privacy Plan**
$E_{O\&M}$ [kWh/year]	0.4	0.15	0.8	0.55
$E_{Transport}$ [kWh/year]	5	5	10	10
Total Operational Energy [kWh/year]	5.4	5.15	10.8	10.55

Table 9.2: Operational Embodied Energy

Substituting the values indicated in the tables above in equation 9.1 results in the energy payback time indicated in figure 9.3.

Table 9.3: Energy Payback Time in Years

	Basic	**Basic and Add-On (Privacy)**
Average Energy Payback Time [years]	**2.1**	**2.1**
Energy Payback Time [South]	2	1.5
Energy Payback Time [West]	2.7	2
Energy Payback Time [East]	2.7	2

Table 9.3 shows the average energy payback time assuming the weighted electricity generation calculated in the electricity yield section. The values for a unit facing South, East, and West are also indicated. Because the system under study requires more material for the mounting structure and requires frequent transport and maintenance, the energy payback time found is slightly higher than that of a rooftop system with an energy payback time approximated at 1.1 to 1.2 years [56]. However, it

is worth noting that the payback period results indicate that the business model under study can recover the energy required to produce it after around 2.1 years for both subscription plans which is still relatively low and close to that of the rooftop PV system.

The processes involved in raw material extraction, manufacturing, transport, and maintenance necessary for the operation of the business model consume significant energy. As a result, these activities contribute to carbon emissions. Hence, it is crucial to compute the carbon footprint associated with the subscription plans of this business model, as will be discussed in section 9.2.2.

9.2.2. Carbon Footprint Hotspots

To quantify the emissions of the business model, the CO2 emission rate equation was used, as shown below. This metric is useful in determining the effect of global warming caused by the adopted business model, allowing it to be compared to the electricity emitted by the grid. The greenhouse gas (GHG) emissions throughout the life cycle of the balcony PV system are aggregated as an equivalent of CO2 reference over a time horizon of 100 years.

$$\text{CO}_2 \text{ emission rate } \left[\frac{g_{\text{CO}_2}}{\text{kWh}}\right] = \frac{\text{Total CO}_2 \text{ emission during life-cycle } [g_{\text{CO}_2}]}{\text{Annual power generation [kWh/year]} \times \text{Lifetime [year]}} \tag{9.2}$$

Raw Material Extraction and Manufacturing

To perform this analysis, numerous life cycle assessments (LCAs) of PV panels were used.

PV Panel

One of the recent Life Cycle Assessments (LCAs) showed that a PERC PV module (Glass-Back Sheet) with an efficiency of 21% manufactured in Europe has CO2e emissions equal to around **14.28 g CO2/kWh**, including transport [29]. It is worth mentioning that the modules selected are assumed to be produced in Europe to ensure minimal greenhouse gas emissions, as these panels are estimated to emit 30 to 40% less emissions compared to panels produced in China [74].

Mounting Structure

One of the main differences between the balcony PV system under study and a rooftop solar system is the design and material of the mounting structure. In fact, the weight of aluminum needed per panel area for a rooftop mounting structure is 2.2-2.6 kg/m². In the case of the balcony PV system the material used is galvanized steel and the design requires 11 and 4.7 kg/m² for the Basic and Add-On units, respectively [85] [92].

According to the IDEMAT Database (2024), the total carbon emissions of aluminum and galvanized steel are 8.67 and 2.3 kg CO2e/kg, respectively. Consequently, calculating the total mass of CO2 emitted by each module area shows that the total emissions from the additional weight of the design and the employment of galvanized steel led to 33% higher emissions for a Basic unit compared to a rooftop PV system. On the other hand, the Add-On unit was found to have a reduction of 58% in carbon emissions compared to the rooftop system, as the weight for the privacy screen support structure uses only 2 kgs of material.

According to IEA PVPS and other sources, the mounting structure of the system accounts for 20-30% of the emissions generated by the production of a PV panel [2] [112]. Hence, the emissions caused by the production of a rooftop mounting structure are around 5 to 6 g CO2e/kWh. If galvanized steel is used, then this increases the value by around 33% for the Basic unit and reduces it by 58% for the Add-On unit, leading to a total of 8 and 3.5 g CO2e/kWh, respectively [112] [74]. It is important to note that the mounting structure has multiple railing and PV clamps which are expected to increase the emissions by around 20 and 10% for the Basic and Add-On units, respectively. This results in a total of 10 and 4 g CO2e/kWh for each system. Under regular maintenance, this mounting structure can last around 75 years. Hence, assuming that the lifetime of the PV panel is 25 years, this reduces the energy required to produce the structure to around 3.5 and 1.5 g CO2e/kWh for the Basic and Add-On units, respectively. It is worth mentioning that since the emissions are computed per kWh, the Basic plan will have the same emissions as a Basic unit of **3.5 g CO2e/kWh**. The Privacy plan on the other hand consists of a Basic and an Add-On unit, hence calculating the weighted average of this plan leads to around **2.6 g CO2e/kWh**.

Inverter and Cables

In addition, the inverter, cables, and electrical components account for around 30% of the PV panel's emissions, adding 4.2 CO2e/kWh for each of the Basic and Privacy plans [10] [145]. This is mainly caused by the fact that each plan consists of one microinverter.

As a result, the total emissions emitted by extracting and manufacturing the balcony PV system are equal to approximately 22 and 20 g CO2e/kWh, for each of the Basic and Add-On units. It is worth mentioning that since the emissions are computed per kWh, the Basic plan will have the same emissions as a Basic unit of **22 g CO2e/kWh**. The Privacy plan on the other hand consists of a Basic and an Add-On unit, hence calculating the weighted average of this plan leads to around **21 g CO2e/kWh**.

Transportation

Another significant contributor to the emissions of the PaaS business model is the transportation from the company's warehouse to the customers, as this takes place every couple of years depending on the contract period. To calculate these emissions, lightweight commercial vehicles were considered as the medium of transport. According to CBS (2022), these vehicles emit around 207 g CO2e/km [19]. Assuming that the vehicle's capacity is 32 units, and that to deliver all these units to their respective customers a total of 32 km must be driven. Consequently, the total emissions will be around 207 g CO2e/roundtrip for each of the Basic and Add-On units. Dividing this number by the insolation of an average European location assumed for a rooftop solar PV system (1391 kWh/m2.year) results in 0.8 g CO2e/kWh.trip for both units. Under the worst-case scenario, all customers will subscribe for 2 years. However, considering that some contracts can have a longer period that can reach 5 years or more, the estimated transportation of each unit was assumed to happen every 3 years. So, assuming a lifetime of 25 years for the system, then the total emissions throughout the system's lifespan caused by transporting a unit within the Netherlands is approximately 6.7 g CO2e/kWh for the Basic and Add-On units. This leads to a total of **6.7 g CO2e/kWh** for the Basic and Privacy plans [2].

Maintenance

One of the main benefits of the PaaS business model is that the company offering the product ensures that the product is maintained regularly after each use (assumed to take place on average every 3 years). The total carbon emissions attributed to this process throughout the full lifetime of the system are estimated to form 2% of the total emissions of a system for the Basic and 1% for the Add-On unit. Consequently, the total maintenance emissions of the Basic and Add-On units are 2 and 1 g CO2e/kWh, respectively. This leads to a total of **2 and 1.5 g CO2e/kWh** for the Basic and Privacy plans, respectively.

Electricity Yield

After identifying the carbon emission hotspots in the PaaS business model as a function of the electricity yield of a rooftop system, a total of around **30 and 29 g CO2e/kWh** was found for the Basic and Privacy plans, respectively. However, this value is not representative of the total emissions of this business model, as the electricity yield of the balcony system is lower than the yield generated by a PV rooftop system.

The main differences are:

1. Sub-optimal Operating Conditions:

[2] Reminder: The Basic plan consists of 2 Basic units and the Privacy plan of 1 Basic and 1 Add-On units

- The tilt of the basic and privacy balcony PV panels is at 80 and 90◦ respectively, meaning it is not optimal like the case of a rooftop PV system.
- The balcony system is more likely to be subjected to shading caused by the surrounding environment.

2. Discontinuous Period / Downtime:

- The system has a downtime of around five days per year, to allow for delivery to the next customer. To account for this downtime, the yield was reduced by around 2% assuming the daily yield is the same for all the days of the year.

3. Different Location:

- The emission values obtained are based on a location with solar irradiation of $1391kWh/m^2.year$, which is higher than the average solar irradiation of $1000kWh/m^2.year$ recorded in the Netherlands.

Therefore, to obtain the actual total emissions per kWh of each plan [g CO2e/kWh.plan] accounting for the difference in electricity yield, the previously obtained 48 and 45 g CO2e/kWh values of each plan were multiplied by the total electricity yield $E_{RooftopPV}$.

The reference yield of the PV rooftop system $E_{RooftopPV}$ [$kWh/m^2.year$] was calculated based on the following assumptions and using equation 9.3:

- *Solar Irradiation (I):* $1391kWh/m^2.year$
- *Module Efficiency: 21%*
- *Time Period (T): 30 years*
- *Performance Ratio (PR)= 0.8*
- A_i*: Active Area of unit ”i”*

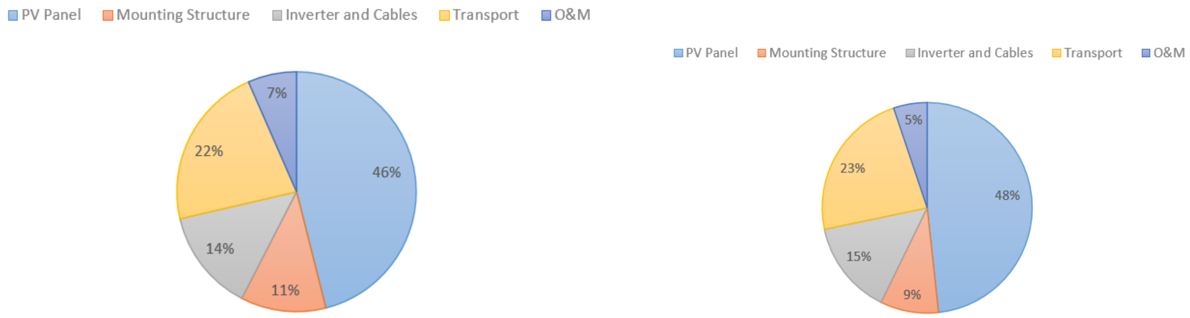
$$E_{\text{Yield Rooftop PV}} = \sum_{y=1}^{T} (I \times \eta \times A_i \times PR_y) \tag{9.3}$$

The resulting values represent the total emissions of the Basic and Privacy plans with a unit of g CO2e. Afterward, the total carbon emissions were divided by the electricity generated by the Basic and Privacy plans equivalent to 3134 and 2693 kWh for the 25-year period. This results in emissions of **77.9 and 77.8 g CO2e/kWh** for the Basic and Privacy plans. These values are then compared with the emissions of a rooftop PV system. According to Muller (2021), a rooftop PV system produced in Europe (excluding EoL) and under $1391kWh/m^2.year$ is equivalent to around 23.2 g CO2e/kWh [74]. However, in the Netherlands, the solar irradiance is around $1000kWh/m^2.year$, leading to total emissions of around 31 g CO2e/kWh for a rooftop PV system.

Carbon Footprint [g CO2e/kWh]	Basic Plan	Privacy Plan	Rooftop PV
	77.9	77.8	31

Table 9.4: Carbon Footprint of Basic, Privacy and Rooftop PV

The contributions of the different components of the business model for the Basic and Privacy subscription plans are shown in figures 9.2a and 9.2b, respectively.



(a) Carbon Footprint Contribution of Different Business Model Components for the Basic Plan

(b) Carbon Footprint Contribution of Different Business Model Components for the Privacy (incl. Basic) Plan

Figure 9.2: Carbon Footprint Contribution of Different Business Model Components for Privacy Plan

To conclude, the carbon footprint of the business model under study was found to be around **77 g CO2e/kWh** for each of the Basic and Privacy plans. These values are higher than that of a conventional rooftop PV system in the Netherlands with emissions of around **31 g CO2e/kWh**. This is mainly caused by the additional weight and type of material used in the mounting structure, the transport emissions of delivering the system, and the lower electricity yield of the balcony PV system [74]. This indicates that the business model developed is less environmentally sustainable compared to rooftop PV systems. However, this business model is targeted at tenants and customers facing obstacles installing rooftop PV systems because of the short-term nature of their contracts and the space constraints imposed by their properties. In the absence of this business model, these end-users will have to rely on the grid to satisfy their electricity consumption which has a carbon footprint ranging between **355 and 420 g CO2e/kWh**. Hence, subscribing to the PaaS business model for balcony PV can reduce the carbon footprint for tenants and customers not able to implement a rooftop PV system by around 78 to 81% for each kWh consumed.

10
Conclusion and Recommendations

10.1. Conclusion

Over the past few years, the adoption of solar PV solutions has been consistently increasing in the Dutch residential sector. However, this has not been the case for all segments of the residential sector. Specifically, the tenants of rental properties have been particularly reluctant when it comes to installing PV systems. This is because of the significant obstacles that they face, mainly due to the existing mismatch between the lifetime of typical solar systems and the short duration of their rental contracts. The situation is further exacerbated when those tenants reside in apartments, where space constraints make it difficult to accommodate bulky PV panels. This thesis sought to address this problem by developing a business model that offers tenants a solution designed to overcome the obstacles that they face. In particular, the thesis proposed a solution whereby portable PV systems are offered under the product-as-a-service business model. This way, tenants are relieved from the burden of making a long-term financial commitment associated with purchasing a relatively expensive PV system. Not only that, but the portable nature of the product means that it can be easily installed without taking up much space, making it suitable for apartments with access to open spaces. The development of the aforementioned business model was guided by the following research question:

”How can the Product-as-a-Service business model for portable PV systems be profitably applied to encourage the adoption of solar PV among renters with short-term contracts while boosting the circularity of the Dutch PV sector?”

Accordingly, this thesis aimed to develop a business model that can be both profitable for companies and attractive to its target customers, while applying strategies intended to promote circularity.

The developed business model relies on a tiered subscription model where customers have the option to choose between two subscription plans: Basic” and “Privacy” subscriptions. Both of these subscriptions are offered under a ”Per-kWh” pricing scheme where customers pay a pre-determined fee for each kWh generated by the PV system. Under this pricing scheme, the two subscriptions were found to have a levelized cost of electricity (LCOE) smaller than the wholesale electricity price of 0.34€/kWh, guaranteeing a margin that the service company and the end-users can benefit from for every generated kWh.

Conducting a financial assessment revealed that, from the company’s perspective, the proposed solution achieves positive net present values for both plans, reflecting their profitability. Moreover, the assessment showed that the internal rate of return falls within the WACC benchmark range for solar projects, further indicating the financial viability of the business model. From the perspective of end-users, the business model was found to result in positive cost savings of 12 and 17 €/year.plan for the Basic and Privacy plans respectively. Therefore, the business model was found to be profitable for both the end-users and the company. Nevertheless, it is worth mentioning that the cost savings for end-users are not particularly high. However, the offered product compensates for that by providing value by enhancing the aesthetics and the privacy of balconies while generating clean electricity.

The environmental impact of the business model was also assessed by evaluating its carbon footprint and energy payback period. It was found that the Basic and Privacy subscriptions have a footprint of 77 g CO2e/kWh respectively. Compared to a conventional rooftop system, the business model was found to have a higher footprint and energy payback period, mainly because of the additional yearly shipment and maintenance processes. However, compared to the electricity grid, the products exhibited a 78-81% reduction in emissions. Since it is not targeted to end-users able to install a rooftop PV system, this implies that the business model has a lower environmental impact if adopted compared to the case where it's not. Moreover, by applying business strategies to extend the lifetime of the product and close its material loops, the system was found to help minimize the material footprint of the PV system, contributing to a boost in PV circularity.

In terms of impact, since the product is offered as a service, this PaaS business model allows the companies adopting it to tap into a previously untapped market segment: "renters with short-term contracts" with an emphasis on apartments. By allowing renters to adopt solar energy solutions, the business model aids in increasing the capacity of solar PV capacity in the country. Increasing this capacity plays a crucial role in lifting the cumulative PV capacity in the country, hence allowing it to reach its energy goals while ensuring cost savings from the side of the customers and profit for the companies. In addition, the nature of the PaaS business model and its alignment with the objectives of the circular economy acts as a booster to the circularity of the PV industry by encouraging reliance on business strategies to extend the lifetime of the product.

More generally, this research highlights a novel approach to solar energy solutions and practices in urban areas, where the reach of conventional renewable solutions is limited. Consequently, the outcomes of this research serve as a blueprint for stakeholders, especially investors and energy companies to adopt the business model by assessing the financial viability of the project and by suggesting steps and recommendations to integrate this research into practice. Moreover, valuable data on consumer needs and preferences were collected to highlight the main criteria to focus on in the case of similar applications, providing initial design directions and criteria to optimize the business model. Additionally, this work adds to the body of knowledge in the field of renewable energy and sustainability by contributing to broadening the space of sustainable energy solutions and practices. Finally, this study can promote sustainability and circularity by giving energy service providers/companies the incentive to enhance PV lifetime and create partnerships with manufacturers and other involved companies.

10.2. Recommendations

The period in which this study was conducted was only 8 months, meaning that the level of detail in the chapters is constrained. Consequently, this chapter identifies crucial areas that should be considered for future research.

First, it is worth mentioning that the calculations made in the study are based on various assumptions, especially in terms of financial assessment, and environmental impact. Examples of these assumptions are the shipment distances, maintenance costs and frequency, irradiance levels, shading factors, wholesale electricity market prices, and status of potential companies adopting the business model among other assumptions. These assumptions could vary in real-world scenarios which can affect the cost structure, electricity yield, and carbon footprint of the business model. Small adjustments in these assumptions could affect the attractiveness of this business model by affecting its cost-effectiveness and profitability to stakeholders. Thus, there exists a fine line in the pricing structure that requires careful considerations and assumptions to ensure a profitable and attractive business model.

Secondly, the end-users' needs and preferences were gathered by conducting surveys and interviews which can only target a limited number of participants. This means that the methods used fail to represent the entire target population and all their preferences and concerns. A recommendation here could be to rely on additional methodologies such as focus groups, additional interviews, and surveys targeting the larger population.

Thirdly, due to limited participation from companies offering similar products and services, only one interview was conducted. Therefore, conducting additional interviews with competitors or similar companies can provide a better understanding of their needs and preferences, and help tailor the business model accordingly.

Additionally, an important consideration is to explore the economic and technical impact of the large-scale adoption of the business model. This consideration can help better understand its effect on the local energy market and utility infrastructure.

Moreover, as mentioned in the literature review chapter, there exists no clear law on the permits and requirements for installing PV panels on balconies. This lack of clarity affects the maximum number of subscriptions that each end-user can subscribe to which could limit the cost savings and profits of the business model. Thus, more effort is needed to identify these laws and the maximum allowed balcony PV capacity. This can be done by conducting interviews with members of the homeowners' association (VvE) and other policymakers.

Moreover, adequate installation manuals should be provided to guarantee a hassle-free and straightforward DIY installation and removal process. An example of an installation guide includes video tutorials with step-by-step instructions to visually assist the customers and make the process engaging.

Finally, in the evaluation of the final concept chapter, end-users were interviewed to identify their interests, concerns, and suggestions which were key in improving the weak points of the business model. However, because of time constraints, only end-users had the chance to give their opinions which ignores the perspective of other primary stakeholders such as companies, investors, and policymakers. A recommendation could be to present the business model to these stakeholders and use their feedback and concerns to further improve the business model.

11

Personal Reflection

This research not only participated in academic research but also was a major step in my personal growth. On a personal note, this research has exposed me to a new perspective of thinking by introducing me to the world of industrial design. Throughout this process, I tackled business, design, and technical aspects, allowing me to visualize how different fields support each other to form a coherent business model that can be applied in real-world situations. Throughout my academic career, I have always been interested in projects that focus on incorporating multiple disciplines. This was the reason behind choosing to apply for this project, which turned out to be a perfect fit that matches my interests and future career plans, and I am grateful that I had the opportunity to participate in it.

While this thesis project was both enjoyable and significantly broadened my expertise across various fields, it also presented its share of challenging moments. For instance, I faced numerous challenges in developing business model concepts as they required an understanding of design concepts which I lacked. This caused me to lose significant time trying to figure out and gain an understanding of these concepts. However, my supervisors helped me overcome these challenges by motivating me and providing constructive feedback. In addition, my supervisor from the Industrial Design Engineering (IDE) faculty provided me with a design book containing all the design concepts and methodologies required to support me in this phase of the project. This book changed my perspective on things, as I realized that designing a business model entails multiple steps before jumping to the technical and financial aspects. In addition, throughout the project, I had to conduct interviews and surveys with strangers and listen to their concerns and preferences. This kind of exposure improved my understanding of the project and opened my eyes to ideas that I could not get to on my own.

Another challenge I faced was setting an unrealistic timeline for the project. Even though I ended up completing all the parts I planned to accomplish, I was not able to stay on track with the set timeline. This pushed me to finish a huge part of the report in the last period of the project. However, working hard and doubling my efforts allowed me to surpass these challenges without compromising the quality of my work. All of this was not possible without the consistent help and motivation provided by my supervisors.

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A

Potential Customer Survey Questions

Question	**Response Options**
1. Please indicate your age group:	- 18-24 - 25-34 - 35-44 - 45-54 - 55-64 - 65 years old and above - Prefer not to say - Other
2. In which type of area do you reside?	- Urban - Suburban - Rural - Prefer not to say - Other
3. How many people currently reside in your household?	- 1 resident (living alone) - 2 residents - 3-4 residents - 5-6 residents - More than 6 residents - Prefer not to say
4. What is your household's annual income bracket?	- Less than $25,000 - $25,000 - $49,999 - $50,000 - $74,999 - $75,000 - $99,999 - $100,000 - $149,999 - $150,000 - $199,999 - $200,000 or more - Prefer not to say
5. Do you live in rental or owned property?	- Rental - Owned - Prefer not to say
6. If you live in a rental property, what is the type of your contract?	- Temporary - Indefinite - Other
7. If temporary, please specify the period:	- 1 year - Other

Question	Response Options
8. How frequently have you relocated, on average, over the past decade?	- Not at all - Once - 2 times - 3 times - 4 times - 5 times - More than 5 times
9. What type of property do you live in?	- Detached house - Semi-Detached - Terraced/townhouse - Apartment - Houseboat - Studio - Prefer not to say - Other
10. Do you have a solar PV system installed?	- Yes - No
11. If no, are you interested in installing a solar PV system in your home?	- Yes - No
12. If you have a solar PV system installed or you are interested in installing one, what are/would be the primary motivations for installing it? (Select up to 2 options)	- Reducing electricity bills - Environmental benefits - Energy independence - Increasing property value - Other
13. If no system is installed, what factors currently hold you back from installing solar panels on your property? (Select up to 2 options)	- High Initial Investment - Lack of Information about Solar - Rental Property Restrictions - Spatial Constraints and other Technical issues - Regulatory Restrictions - Aesthetic Concerns - Questionable Benefits - Other
14. What is your household's average annual electricity consumption?	- Less than 1000 kWh - 1000-1999 kWh - 2000-2999 kWh - 3000-3999 kWh - 4000-4999 kWh - 5000-5999 kWh - More than 6000 kWh - Don't know
15. How concerned are you about energy costs fluctuating/increasing in the future?	- Extremely concerned - Very concerned - Moderately concerned - Slightly concerned - Not concerned

Question	Response Options
16. How important is reducing climate change to you personally?	- Extremely important - Very important - Moderately important - Slightly important - Not important
17. Are you aware of the various financial incentives available in the Netherlands for residents wishing to adopt solar PV systems?	- Yes - No
18. How concerned are you about the discontinuation of the net metering program?	- Extremely concerned - Very concerned - Moderately concerned - Slightly concerned - Not concerned at all
19. Do you have a balcony/shed on which you can install such a system?	- Yes - No
20. What are the most attractive features of portable solar PV systems as compared to conventional PV systems? (Select up to 2 options)	- Cost-effectiveness - Compact size - Ease of installation - Aesthetic appeal - Other
21. To what extent do you believe that the installation of a portable PV system influences the aesthetic appeal of residential buildings?	- Significantly enhances - Slightly enhances - Neutral - Slightly detracts - Significantly detracts
22. How much would you be willing to adjust your energy consumption behavior (such as using more energy during sunlight hours) if you had a portable solar PV system installed?	- Significantly adjust - Moderately adjust - Slightly adjust - Not willing to adjust - Not applicable/Don't know
23. Have you heard of the Product as a Service (PaaS) model for solar PV systems, where you lease them as a service instead of purchasing them?	- Yes - No
24. Would you be open to leasing a solar system rather than owning one?	- Yes - No - Not sure
25. What is the most attractive feature of leasing instead of buying?	- Low upfront cost - Sustainability - Flexibility - All-inclusive maintenance - Short-term contracts - Other
26. What are the main drawbacks of leasing instead of buying?	- Cost considerations - Limited ownership - Dependence on service providers - Privacy and data security concerns - Limited customization options - Other

Question	Response Options
27. What concerns, if any, do you have about leasing a portable solar PV system through a PaaS model?	- Liability concerns - Clarity on maintenance - Cost difference long term - Accidental damage - Lack of clarity - Other
28. Are you aware of any adverse environmental effects linked to solar PV systems? If yes, please specify in other.	- Yes - No - Other
29. How important are the negative environmental impacts of solar PV systems to you when considering their installation?	- Extremely important - Very important - Moderately important - Slightly important - Not important
30. How open are you to leasing second hand or repaired solar PV panels?	- Very positive - Somewhat positive - Neutral - Somewhat negative - Very negative - Other
31. How do you currently get your information for energy solutions?	- Internet - Friends/Family - Energy Providers - Government Sources - Other
32. If you have previous experience with residential solar PV systems, please share your feedback or lessons learned.	- Open Question
33. Please share any additional thoughts or concerns you have regarding portable solar PV systems or the leasing model.	- Open Question

B

Potential Customer Interview Questions

1. Are you familiar with portable PV systems?
2. Have you considered the option of portable PV systems for places like balconies or sheds? What factors influenced your consideration or reluctance?
3. What do you think about the effect of portable PV systems on the aesthetics of the building?
4. What would be potential motivations for you to consider a PV system?
5. What holds you back from adopting a PV system?
6. Do you have any experience with leasing products?
    - What type of product was this?
    - How was your experience with leasing this product?
    - Were there any specific preferences or concerns you had?
    - Do you still lease this product? Why (not)?
7. Have you heard about leasing a PV system? What are your initial impressions concerning it?
8. In your opinion, what features make leasing a PV system appealing?
9. Are there any specific features or services that would make you more inclined to lease a PV system?
10. Do you have any concerns about leasing a PV system?
11. What are your thoughts about leasing secondhand PV panels with slightly reduced efficiency but potentially at a cheaper price? How would you weigh this choice?
12. Do sustainability and environmental impact affect your decision to adopt a PV system? If so, how?
13. Does the low energy output of the system affect your decision in subscribing to the service?
14. Would you consider leasing a PV system if you have a short-term contract period for your rental home (e.g. 1-3 years)?
15. If you were to relocate, would the ability to move the system with you be a significant factor in your decision to lease?
16. Does the potential for higher long-term costs affect your decision to lease a PV system?
17. Do you think the length of a leasing contract might influence your decision? In what ways?
18. Would the option to purchase the panels after the lease term impact your interest in any way? If so, how?
19. Concerning the pricing strategy, would you prefer a fixed subscription payment or a pay-per-use model?
20. Would you be willing to adjust your energy consumption to align with the energy production from a portable solar PV system?

C

Solar Panel Leasing Firms Interview Questions

1. Tell them a bit about what you know about the company. Can you please tell me more about the company?
2. Can you describe your solar PV systems leasing model? (Pricing Scheme and Typical Duration of Contract Periods)
3. Does the system rely on the net metering scheme when excess energy is sent back to the grid?
4. What is your policy or practice for solar panels at the end of their lifecycle? Do you currently collaborate with companies tasked with managing end-of-life solar panel disposal? Or at the end of the contract.
5. What do you think makes leasing more attractive to customers? What are the main motivations?
6. Are you aware of any concerns the customers have concerning leasing solar systems? (dependence on energy providers, limited ownership, cost considerations, etc…)
7. Which sectors or types of customers show the most interest in leasing solar PV systems?
8. What is your perception of the PV leasing market? Is it easy or difficult to enter it? Why?
9. What current trends are you observing in the leasing market for solar PV systems? (Is the demand increasing? Is the market growing? Etc…)
10. Do you know any other companies offering PV leasing services?
11. Are there any subsidies or incentives available for companies undertaking residential solar leasing projects?
12. How do you usually monitor the performance of the installed PV system?

D

Electricity Yield Estimations of Suggested Concepts

Assumptions

- Optimal Angle: 60 Degrees
- Efficiency: 21%
- Netherlands Coordinates: 52° N, 5° E
- Shading Factor is only considered in concept 4 with a value of 70% to account for shade caused by the objects placed on the table support and the surroundings.
- Irradiance and Solar Angle Data imported from SolCast, European Commission.

Formulas

- Direct solar radiation:

$$G_{\text{direct}} = DNI \cdot \cos(\text{AOI}) \cdot SF$$

- Diffuse solar radiation (Isotropic Sky Model):

$$G_{\text{diffuse}} = SVF \cdot DHI$$

- Reflected radiation from surrounding surfaces:

$$G_{\text{albedo}} = (1 - SVF) \cdot \alpha \cdot GHI$$

- Sky View Factor:

$$SVF = \frac{1 + \cos(\theta_m)}{2}$$

- Total irradiance on the surface:

$$G_{\text{total}} = G_{\text{direct}} + G_{\text{diffuse}} + G_{\text{albedo}}$$

Note: These calculations are just an estimation to calculate and compare the LCOE of generated concepts and were not considered nor used after selecting the final design. These electricity yield values do not take into account the performance factor, efficiency of the inverter, and efficiency of the cables.

Concept/Orientation	**South**	**East/West**
Energy Yield of Concepts 1 and 3 (Vertical) [kWh/m^2.y]	171	132-133
Energy Yield of Concepts 2 and 5 (Optimal Tilt) [kWh/m^2.y]	225	169-171
Energy Yield of Concepts 4 (Horizontal) [kWh/m^2.y]	143	143

E

Levelized Cost of Electricity

The Levelized Cost of Electricity (LCOE) is given by the equation:

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{E_{t,el}}{(1+i)^t}}$$

where:

- I_0 is the capital expenditure in euros.
- A_t is the operational cost in euros for year t.
- $E_{t,el}$ is the produced amount of electricity in kWh per year t.
- i is the interest rate in [%].
- n is the economic lifetime [years].
- t is the year of the lifetime (1, 2, ..., n).

F

Levelized Cost of Electricity of Generated Concepts

Note: These calculations and assumptions are not accurate and are based on high-level estimations, as they were only used to rank the concepts in terms of LCOE. These assumptions and values were not used in the second part of the report (after selecting the final concept).

Assumptions

1. i= 7% [138].
2. Panel degradation factor= -0.5%.
3. Maintenance is 2% of initial investment cost [75].
4. Electricity Yield values of the south orientation.
5. Replacement costs were accounted for in the cost structure but are not mentioned in this Appendix.

Calculations

Table F.1: Concepts Comparison

Concept	I_0	A_t	$Et_{L,el}$	n	LCOE (euros/kWh)
1	200	4	171	15	0.1
2	150	3	225	30	0.04
3	400	8	171	25	0.15
4	250	5	143	20	0.1
5	300	5	225	20	0.09

G
Conceptualization Mind Map

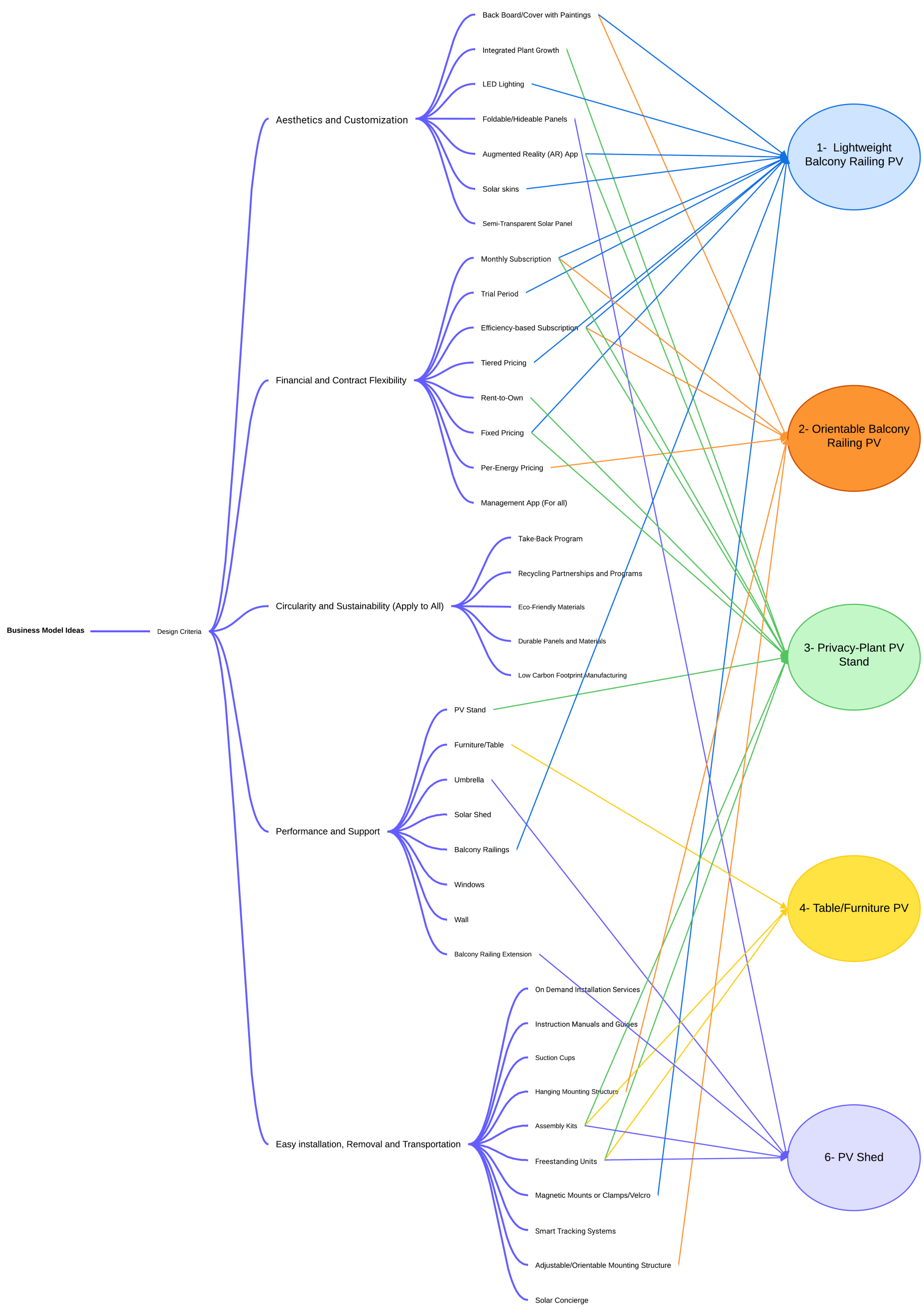


Figure G.1: Mind Map

H

Financial Metrics

H.1. Net Present Value (NPV)

$$\text{NPV} = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t}$$

where:

- CF_t: cash flow at time t,
- i: discount rate,
- T: lifespan of the system.

H.2. Internal Rate of Return (IRR)

$$\sum_{t=0}^{T} \frac{CF_t}{(1+\text{IRR})^t} = 0$$

where:

- CF_t: cash flow at time t,
- IRR is the Internal Rate of Return, which is the discount rate for which the NPV=0.

By solving this equation, the IRR is obtained.

H.3. Payback Period

$$\text{Payback Period} = \text{Smallest } n \text{ for which } \sum_{t=0}^{n} CF_t \geq 0$$

This equation finds the smallest period n after which the cumulative cash flow becomes non-negative.

H.4. Discounted Payback Period

$$\text{Discounted Payback Period} = \text{Smallest } n \text{ for which } \sum_{t=0}^{n} \frac{CF_t}{(1+i)^t} \geq 0$$

This equation finds the smallest period n after which the discounted cumulative cash flow becomes non-negative.

I

PV Panel Datasheet

Figure I.1: PV Panel Basic Unit 1

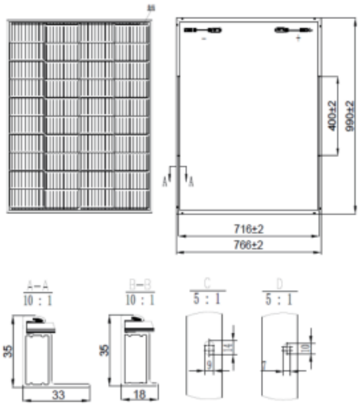
145-150W SP-M10/40H

ELECTRICAL CHARACTERISTICS (STC)

Maximum Power (Pm)	W	145	150
Power Tolerance	W	0~+5	
Maximum Power Voltage (Vm)	V	23.08	23.32
Maximum Power Current (Im)	A	6.28	6.43
Open Circuit Voltage (Voc)	V	27.58	27.81
Short Circuit Curren (Isc)	A	6.80	6.85
Module Efficiency (ηm)	%	19.12	19.78

STC:AM=1.5, irradiance=1000W/m², module temperature=25℃

TECHNICAL DRAWING

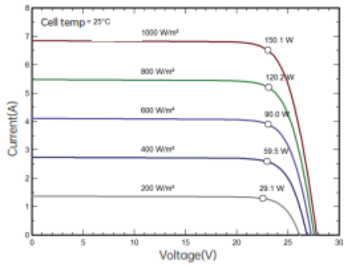


MECHANICAL SPECIFICATIONS

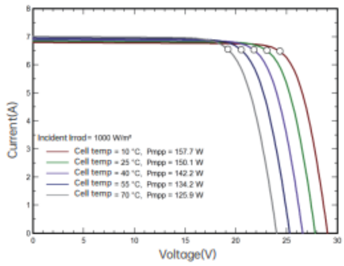
External Dimension (L×W×H)	990×766×35mm
Solar Cells	40 (4x10)/10BB Mono/182×91mm
Weight	8.3kg
Glass	3.2mm AR-coating heat-strengthened glass
Frame	Anodized aluminum alloy, silver color
Junction Box	IP68
Output Cables	4mm², 300mm or customized length
Connector	MC4 Compatible

I-V CURVE

I-V characteristics at different irradiance (SP-M10/40H150W)



I-V characteristics at different temperatures (SP-M10/40H150W)



APPLICATION CONDITIONS

Maximum System Voltage	DC1500V (IEC)
Maximum Series Fuse Rating	15A
Operating Temperature	-40℃ ~ +85℃
Mechanical Load	5400Pa/2400Pa
Hail Test	25mm diameter hail at 23m/s
Application Rating	Class A

TEMP CHARACTERISTICS

Nominal Module Operating Temperature	45±2℃
Temperature Coefficient of Power	-0.35%/℃
Temperature Coefficient of Voltage	-0.28%/℃
Temperature Coefficient of Current	0.05%/℃

PACKING CONFIGURATION

Container	40'HC
Module per box	31 Pieces
Packaging Box Size	1020×1140×900mm
Module per Container	1364 Pieces

SOLAR N PLUS NEW ENERGY TECHNOLOGY CO., LTD

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www.solarnplus.com

Solar N Plus reserves the sole right of interpretation.
Version No.2023V2.0

Figure I.2: PV Panel Basic Unit 2

Figure I.3: PV Panel Add-On Unit 1

115-120W SP-M10/32H

ELECTRICAL CHARACTERISTICS (STC)

Maximum Power (Pm)	W	115	120
Power Tolerance	W	0~+5	
Maximum Power Voltage (Vm)	V	18.44	18.70
Maximum Power Current (Im)	A	6.24	6.42
Open Circuit Voltage (Voc)	V	22.02	22.29
Short Circuit Curren (Isc)	A	6.69	6.81
Module Efficiency (ηm)	%	18.68	19.48

STC:AM=1.5, irradiance=1000W/m², module temperature=25℃

MECHANICAL SPECIFICATIONS

External Dimension (L×W×H)	804×766×35mm
Solar Cells	32 (4x8)/10BB Mono/182×91mm
Weight	7.9kg
Glass	3.2mm AR-coating heat-strengthened glass
Frame	Anodized aluminum alloy, silver color
Junction Box	IP68
Output Cables	4mm², 300mm or customized length
Connector	MC4 Compatible

APPLICATION CONDITIONS

Maximum System Voltage	DC1500V (IEC)
Maximum Series Fuse Rating	15A
Operating Temperature	-40℃ ~ +85℃
Mechanical Load	5400Pa/2400Pa
Hail Test	25mm diameter hail at 23m/s
Application Rating	Class A

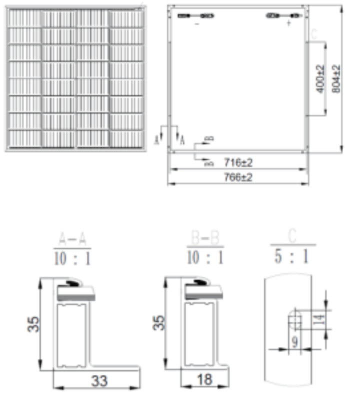
TEMP CHARACTERISTICS

Nominal Module Operating Temperature	45±2℃
Temperature Coefficient of Power	-0.35%/℃
Temperature Coefficient of Voltage	-0.28%/℃
Temperature Coefficient of Current	0.05%/℃

PACKING CONFIGURATION

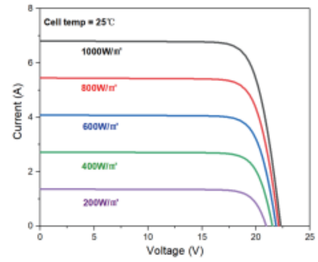
Container	40'HC
Module per box	31 Pieces
Packaging Box Size	834×1140×900mm
Module per Container	1736 Pieces

TECHNICAL DRAWING



I-V CURVE

I-V characteristics at different irradiance
(SP-M10/32H120W)



I-V characteristics at different temperatures
(SP-M10/32H120W)

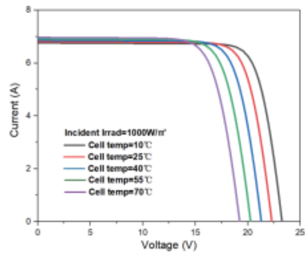


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Figure I.4: PV Panel Add-On Unit 2

J

Inverter Datasheet

hoymiles

Open Energy For All

Microinverter Datasheet

HMS-300-1WB
HMS-350-1WB
HMS-400-1WB
HMS-450-1WB
HMS-500-1WB

Description

The HMS-500-1WB series microinverter is designed to fit various residential spaces such as balconies, terraces, and gardens. It features a built-in Wi-Fi & Bluetooth communication module and can deliver output power up to 500 VA.

Pairing perfectly with the HMS Cable System, the HMS-500-1WB series microinverter offers a hassle-free plug-and-play installation. No complicated wiring is needed - you can set it up within minutes.

Moreover, the new S-Miles Balcony App enhances functionality, enabling effortless customization of your smart home solar system.

Features

01 Provides multiple installation options with its 1-in-1 design and plug-and-play functionality

02 Built-in Wi-Fi & Bluetooth module ensures wireless security and reliability

03 Supports cloud-based or local solar system configurations

04 Works with the S-Miles Balcony app to customize your smart home solar system

05 Meets ETSI EN 303 645 cybersecurity standards for enhanced privacy protection

06 Enhanced safety by using rapid shutdown compliance and an isolated transformer

Region: Europe V202405

hoymiles.com
sales@hoymiles.com

Figure J.1: Microinverter Datasheet 1

Technical Specifications

Model	HMS-300-1WB	HMS-350-1WB	HMS-400-1WB	HMS-450-1WB	HMS-500-1WB
Input Data (DC)					
Commonly used module power (W)	240 to 405+	280 to 470+	320 to 540+	360 to 600+	400 to 670+
Maximum input voltage (V)	60	60	65	65	65
MPPT voltage range (V)	16 to 60				
Min./Max. start voltage (V)	22/60				
Maximum input current (A)	12	13	14	15	16
Maximum input short circuit current (A)	20	20	25	25	25
Number of MPPTs	1				
Number of inputs per MPPT	1				
Output Data (AC)					
Rated output power (VA)	300	350	400	450	500
Rated output current (A)	1.30	1.52	1.74	1.96	2.17
Nominal output voltage/range (V)*	230/180 to 275				
Nominal frequency/range (Hz)*	50/45 to 55				
Adjustable power factor (@nominal power)	>0.99 default 0.8 leading ... 0.8 lagging				
Total harmonic distortion (@nominal power)	<3%				
HMS Plug and Play Cable (Optional)					
Connector type	HMS Field Connector				
Cable size (mm^2)	1.5				
Cable length (m)	3 (customizable)				
Plug type	Schuko				
Efficiency					
Peak efficiency	96.70%	96.70%	96.70%	96.50%	96.50%
Nominal MPPT efficiency	99.80%				
Night power consumption (mW)	< 50				
Mechanical Data					
Ambient temperature range (°C)	-40 to +65				
Storage temperature range (°C)	-40 to +85				
Dimensions (W × H × D [mm])	182 × 164 × 30				
Weight (kg)	1.8				
Enclosure rating	Outdoor - IP67				
Cooling	Natural convection – No fans				
Features					
Communication with cloud	2.4G Wi-Fi				
Communication with local app	Bluetooth				
Topology	Galvanically Isolated HF Transformer				
Interface	LED & App				
Compliance	VDE-AR-N 4105: 2018, EN 50549-1: 2019, VFR 2019, IEC/EN 62109-1/-2, IEC/EN 61000-6-1/-2/-3/-4, IEC/EN 61000-3-2/-3				

* : Nominal voltage/frequency range can vary depending on local requirements.

Figure J.2: Microinverter Datasheet 2

K

Shipment Cost Estimations

Assumptions:

- **Maximum Vehicle Capacity:** 32 parcels/units
- **Plan Configuration:** Each plan consists of 2 parcels.
- **Subscription Rate:** On average each end-user subscribes to 2 plans.
- **Delivery Distribution:** 30% of stops in rural areas and 70% in urban areas.

Distance Calculation

Rural Areas:

- Distance per stop: 10 km
- Number of stops: 8
- Total distance: 10 km/stop $\times$ 8 stops $= 80$ km

Urban Areas:

- Distance per stop: 2 km
- Number of stops: 8
- Total distance: 2 km/stop $\times$ 8 stops $= 16$ km

Weighted Average Distance:

$$\text{Average Distance} = 0.3 \times 80 \text{ km} + 0.7 \times 16 \text{ km} = 24 \text{ km} + 11.2 \text{ km} = 35 \text{ km}$$

Fuel Cost Calculation

- **Fuel Consumption:** 10 km/L
- **Fuel Price:** €1.90 per liter

$$\text{Fuel Consumption per Round} = \frac{35 \text{ km}}{10 \text{ km/l}} = 3.52 \text{ liters}$$

$$\text{Fuel Cost per Round} = 3.52 \text{ liters} \times \text{€}1.90/\text{liter} = \text{€}6.6$$

Maintenance and Insurance Costs

- **Maintenance and Insurance Cost:** 10% of the fuel cost per round

$$\text{Maintenance and Insurance Cost per Round} = 0.10 \times €6.6 = €0.6$$

Total Operating Costs (Excluding Salaries)

$$\text{Total Operating Cost per Round} = €6.6 + €0.6 = €7.2$$

Driver's Salary

- **Driver's Salary:** €12 per hour
- **Total Shpment Time:** 1.5 hours

$$\text{Driver's Salary per Round} = €12/\text{hour} \times 1.5 \text{ hours} = €18$$

Total Cost per Delivery Round

$$\text{Total Cost per Round} = \text{Operating Cost} + \text{Driver's Salary}$$

$$\text{Total Cost per Round} = €7.2 + €18 = €25.2$$

Cost per Parcel

Since each roundtrip consists of 16 plans (32 parcels):

$$\text{Cost per Plan} = \frac{\text{Total Cost per Round}}{16 \text{ plans}} = \frac{€25.2}{16} = €1.5/\text{plan}$$

Hence, the shipment cost including the salary of the driver is estimated to be equal to 1.5€ per Basic and Privacy plan.

L

Sensitivity Analysis

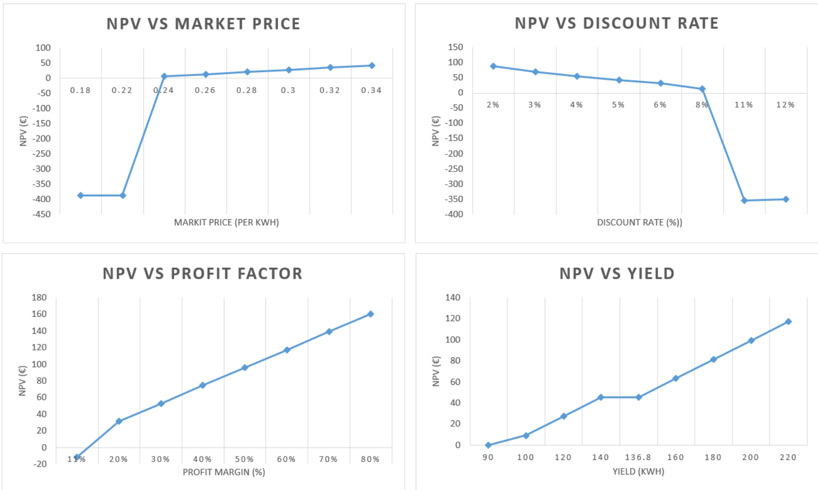

Figure L.1: NPV Change as a function of Input Variables for Basic Plan

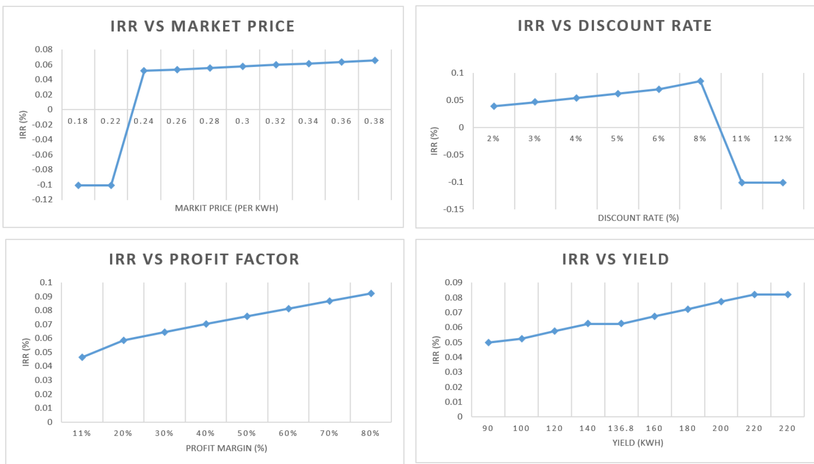

Figure L.2: IRR Change as a function of Input Variables for Basic Plan

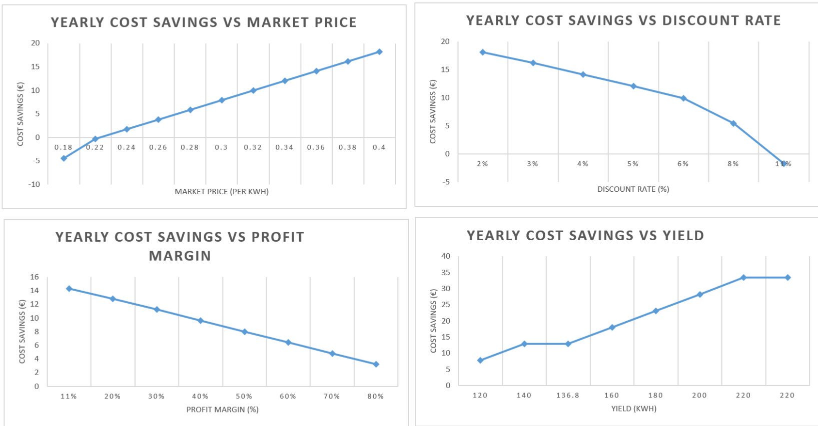

Figure L.3: Cost Savings Change as a function of Input Variables for Basic Plan

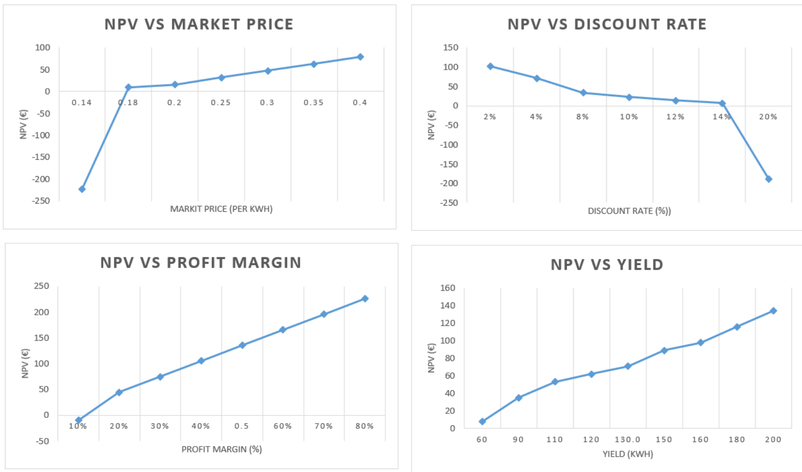

Figure L.4: NPV Change as a function of Input Variables for Privacy Plan

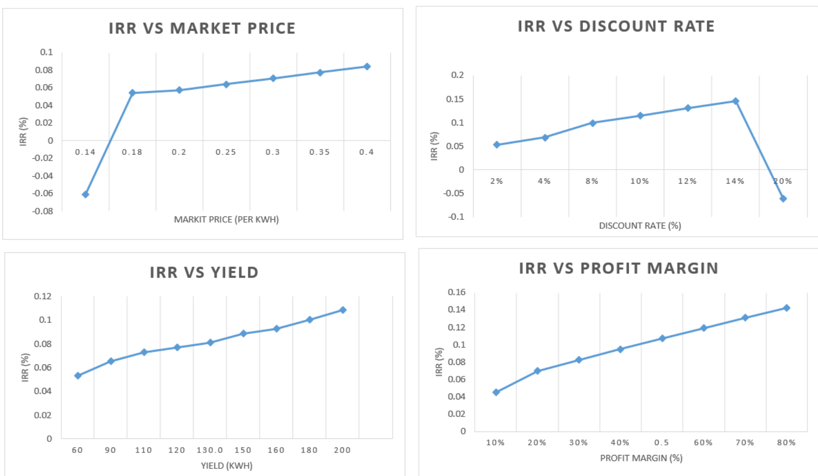

Figure L.5: IRR Change as a function of Input Variables for Privacy Plan

Figure L.6: Cost Savings Change as a function of Input Variables for Privacy Plan

M

Interview Consent Form

You are being invited to participate in a research study titled product-as-a-service for balcony PVs and other systems. This study is being conducted by the master's student Jad Dika from the TU Delft.
The purpose of this research is to develop a product-as-service business model for portable PV systems and to investigate how this model can expand the Dutch solar PV market and boost PV circularity. This interview should take you approximately *20 to 30* minutes to complete. The data will be used to gain a better understanding of your preferences and concerns related to the business model and to identify the different features potential customers look for in a similar business model. We will be asking you about your preferences and concerns, and experience about leasing solar PV systems.

We will minimize any risks by anonymizing the data collected. The data will be recorded on paper notes with only Jad Dika having access to it and will be destroyed after retrieving the needed information. The data collected will be used solely for research purposes.
Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions.

In case of any complaints, please contact me on my email: j.dika@student.tudelft.nl .

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated 15/03/2024, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves providing my personal views on a series of question related to leasing portable solar PV systems that will be destroyed once the relevant information is retrieved.	☐	☐
4. I understand that the study will end in mid-July 2024.		
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
5. I understand that de-identified data collection will be taken to minimise the threat of a data breach and protect my identity in the event of such a breach.	☐	☐
6. I understand that personal information collected about me that can identify me, such as my name, will not be shared beyond the study team.	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		

Figure M.1: Interview Consent Form

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
7. I understand that after the research study the de-identified information I provide will be used in the report on decision-making and product development.	☐	☐
8. I agree that my responses, views or other input can be quoted anonymously in research outputs.	☐	☐
D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE		
9. I give permission for the de-identified data that I provide to be archived in TUD repository so it can be used for future research and learning.	☐	☐

Signatures

_________________________ _________________________ ________

Name of participant [printed] Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_________________________ ____________________ ________

Researcher name [printed] Signature Date

Study contact details for further information: Jad Dika, j.dika@student.tudelft.nl

Figure M.2: Interview Consent Form