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Household's electricity self-consumption maximisation through smart storage and energy flows management

Dutch Business Case Study

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Dutch Business case study: household's electricity self-consumption maximisation through smart storage and energy flows management

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With the completion of this Final Degree Project, I am concluding, for the moment, my academic path, and I am starting venturing in the grown-up world.

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With the backpack full of memories, still thirsty for learning, I'm now ready to advance in my adventure.

Abstract

In this Master Thesis Project, the business case has been studied for solutions able to monitor the energy balance and maximise the electricity self-consumption of Dutch households, in preparation for the gradual phasing out of the net metering policy starting from 2023.

In the initial market research, products investigated were batteries, home energy management systems and hybrid inverters. The selection of the best technologies to offer has been based on several parameters, including the precision offered by the product in managing energy fluxes inside the house, the price, the maturity and system integration possibilities guaranteed by the solution, as well as the reliability of the company and its willingness to partner with Woon Duurzaam.

In order to study the savings guaranteed by each solution, two client profiles have been created, that could represent the general pattern of Woon Duurzaam most common clients in terms of heating behaviour, use of appliances and electricity loads, and solar production. The first client profile is a family composed of 2 adults and 2 kids, while the second client profile is a couple composed of 2 retired seniors. Both profiles where studied considering a detached house. For each client profile, 12 configurations have been created and simulated, changing the thermal performance of the house, the size of the PV system and battery, and considering or not the adoption of an electric vehicle. The hourly electricity consumption, production and storage has been simulated in MATLAB, and the hourly electricity bill has been calculated for 15 years in four different cases: without implementing any smart storage or HEMS solution, with the use of a battery, with the use of a battery coupled with a HEMS, and with the implementation of a HEMS without battery.

Savings and return of investment have been calculated for every case and every configuration, considering three different electricity tariff regimes: flat, conservative peak and off-peak rates, and advanced time-of-use tariff. For the most profitable solution, the payback time has been calculated, and a market proposition designed in order to guarantee profit for the company.

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AC	Alternating Current
BP	Battery Profile
BPRs	Balance Responsible Parties
C	Configuration
COP	Coefficient of Performance
CT	Current Transformer
DC	Direct Current
DHW	Domestic hot Water
DOD	Depth of Discharge
DSO	Distribution System Operator
DSR	Demand Side Response
EPC	Energie Prestatie Coëfficiënt
EV	Electric Vehicle
HEMS	Home Energy Management System
HVAC	Heating,Ventilation and Air Conditioning
ODE	Opslag Duurzame Energie (Sustainable Energy Surcharge)
PBT	Payback Time
PV	Photovoltaics
PVP	PV Profile
ROI	Return of Investment
TR	Tariff Regime
TSO	Transmission System Operator

1 Introduction

1.1 Woon Duurzaam

Woon Duurzaam is a full lifecycle home sustainability solutions provider. The company helps households to become gas-free and has been operating, so far, in the Dutch market exclusively. The company business plan consists of offering the client a free and detailed housing scan, mainly focused on energy performance and heat requirements. Afterward, a customized (tailor-made) energy plan is made in order to make the home energy neutral, by preparing a quotation in which all the costs are clearly charted. Possible measures can consist of installing a heat pump, solar panels and insulating homes. In addition, Woon Duurzaam consultants determine which financing option is the best for the customer to pursue. Indeed, some subsidies have been made available by the Dutch government to support households' transition towards sustainable energy: the company helps homeowners with applying for and receiving these subsidies, but also with reclaiming VAT on solar panels (Woon Duurzaam, 2020).

1.2 Assignment & Scope

Due to the net metering formula, Dutch PV owners can currently sell the surplus of electricity produced to the grid at the same price for which they buy it. From 2023, the net metering formula will be gradually phased out: it will be less convenient for homeowners to inject the unconsumed electricity into the grid, and they will have to maximise their self-consumption in order not to waste the produced energy.

Following this and other imminent changes in the electricity market, the assignment focuses on the design of integrated packages for Woon Duurzaam customers that can efficiently comply with the trend of maximising households' self-consumption. In particular, the business case is analysed for the introduction in the company products portfolio of technologies able to expand Woon Duurzaam proposition with the following proposals:

- **Proposal 1: Self-consumption maximisation**
- **Proposal 2: Energy Monitoring** (products able to monitor Heat Pump consumption, PVs production and Electric Vehicle charging status)

After a preliminary market research focused on identifying the best available solutions, the business case is studied in 3 steps:

- **Step 1: Techno-Economic Model**
- **Step 2: Return of investment Calculation**
- **Step 3: Sales Volume Projection**

The focus will be the investigation of possible Home Energy Management Systems (HEMS) and storage technologies solutions to be implemented, incorporated with PV system, heat pumps and EV (Electric Vehicle) charger.

The typical operation mode of a system composed of PV, inverter and battery consists of using the generated power following this order:

- during the day,
    - the priority is to feed the home loads

    - the extra power is addressed to charge the battery
    - ultimately, if the battery is charged and the loads covered, the surplus is exported to the grid
- during the night,
    - the loads are firstly powered with the battery
    - if it's not enough, loads are covered with the electricity purchased from the grid.

Solutions here investigated are products that can act in a smarter and more innovative way, by balancing the power from PVs, battery and grid according to price of electricity, production prediction based on weather forecast, and consumption prediction. The final goal is to maximise the economic savings resulting from the purchase of the system, by increasing the consumption during periods of low electricity prices and when there's a surplus of solar energy, and by reducing the amount of electricity sold to the grid. The consumption and production pattern of the house after the system implementation should be similar to the one displayed in Figure 1.

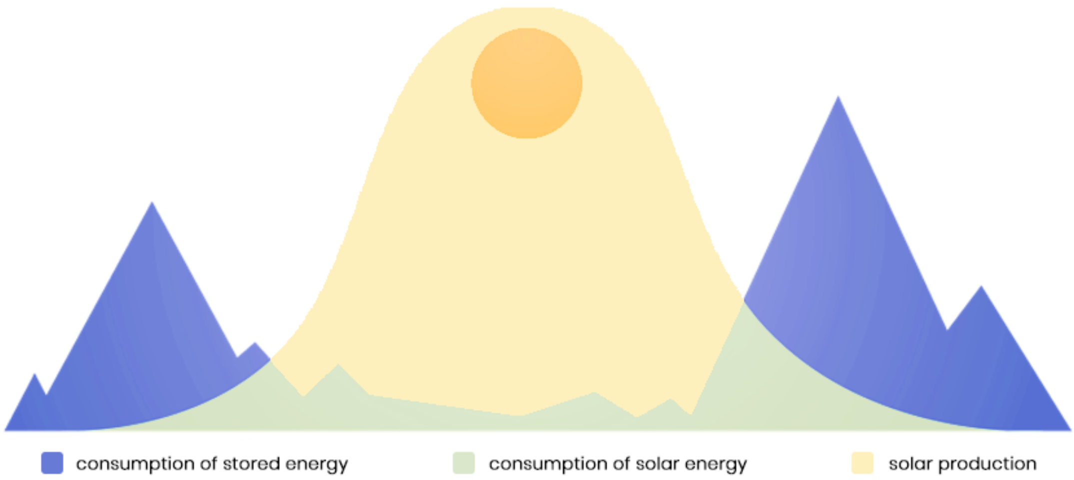

Figure 1: Residential consumption and production with smart storage implementation (Solax, 2020)

The project has the ambition of providing an added value for the company: Woon Duurzaam will not only convert houses into non-CO2 emitting and energy-neutral, but will also make them smart, capable of intelligently storing and delivering energy to and from the grid.

Another goal is to investigate possible monitoring solutions to be sold to customers, in order for the company to improve their maintenance offer.

2 Literature Review

2.1 Dutch Electricity Market

The Dutch energy market is privatized, thus enabling homeowners to choose or change the supplier. The most common energy contracts involve a fixed one-year tariff scheme: at the beginning of the contract, clients make a prepayment, based on the estimated household's energy consumption. At the end of the year, the energy supplier calculates the real energy consumption through meter readings, checking whether the client gets money back or must pay extra. In addition, homeowners pay a fixed annual capacity fee that does depend on the capacity of the grid connection of their home. All capacities from 1x35A up to 3x25A are equally assessed, while from 3x35A the tariff steeply increases (Stedin, 2020).

Smart Meters rollout has been started by the government in 2014, and it is reported that nearly 3 million households were equipped with it by the end of 2016. The objective is to reach the target mentioned in EU Directive 2009/72/EC, with 80% of households having a smart meter by 2020 (Van Aubel, 2019).

Reduced night tariff is available with some contracts from 23:00 – 07:00 and on weekends, from Friday at 23:00 until 07:00 on Monday (Access, 2020).

The final electricity price is the sum of three different components: delivery rate (Leveringstarief), energy tax (Energiebelasting) and storage of sustainable energy and climate transition tax (Opslag Duurzame Energie, ODE). The price of electricity for the first half of 2020 are shown in Table 1:

Table 1: Electricity price components

Electricity tariff component	Price per kWh
Leveringstarief	€ 0,089
Energiebelasting	€ 0,118
ODE	€ 0,033
Total	€ 0,240

In addition, the fixed annual network management costs have to be paid to the network operator.

In the period between 1995 and 2015, the total electricity price has been subject to a 4% increase rate every year, and it is estimated that the trend will be similar until 2030 (van Dijk, 2020).

For customers who self-generate electricity, for example through PV panels installed on the roof, the net-metering formula is applied: electricity that is fed into the grid and consumed at a later stage has the same value, equal to the full consumer price. This means that it does not matter whether electricity is self-consumed directly or first fed into the grid, both have the same price, allowing the grid to be used as a battery (ConsuWijzer, 2020). The net metering policy declares that the power companies are obligated to deduct all the power that a household feeds back into the grid, from the amount of power that it consumes. That means that PV owners only pay for the resulting balance between the two (Zonnefabriek, 2020).

2.2 Research Gap

2.2.1 Electricity Tariffs Changes

The Dutch energy market's picture presented in paragraph 2.1 is subject to an imminent mutation due to some changes in regulations. Some contracts are already beginning to follow the pathways of other European countries. In addition to the reduced night tariff, time-of-use tariffs (also called dynamic tariffs or time-of-day tariffs) are offered: these tariffs incentivise the consumption during the off-peak hours, proposing a cheaper price when the production is high and the demand is low, a higher price when the demand is high and the production low. The popularity of these tariffs' typology is increasing in many European countries, including Sweden, Germany, Finland, France. The main purpose is to help grid's operators in the challenging task of avoiding network congestion through shaves and deferments of peak loads (IRENA, 2019).

2.2.2 Net metering Formula Phasing out

From 2023, the government will gradually lower fiscal incentives to support the sale of surplus self-generated power, as well as net metering tariffs, which are now equal to the full consumer price (Bellini, 2017). The aim is to support the rise of low-voltage grid management: matching renewable energy supply to domestic energy demand, prioritizing locally produced energy (Smale, van Vliet, & Spaargaren, 2017). Another reason behind the change is represented by the losses suffered by the government on tax paid over electricity due to the net metering law. Indeed, a household without solar panels pays VAT over every kWh consumed, whereas a household with solar panels pays VAT only on the electricity it consumes not subjected to the net metering , thus from the net amount they buy. (Zonnefabriek, 2020).

The net metering law will be slowly phased out in stages, decreasing the percentage of energy that is subject to net metering by 9% per year from the year 2023 onward. In the final stage, net metering will be phased out completely from 2031.

In 2023, the percentage of energy that is subject to net metering will fall from 100% to 91%, as is shown in Figure 2. Consequently, 91% of all the electricity fed back into the grid will be deducted from the energy consumed, while the remaining 9% will still get some compensation, reduced compared to the price of the electricity purchased from the grid. There will be a minimum price that a household must receive for power fed back to the grid, labelled by the government as "reasonable compensation' (redelijke vergoeding). So far, it is still unknown how much the 'reasonable compensation' will be, but it will probably be less than 80% of the basic cost of electricity (excluding all taxes and surcharges) (Zonnefabriek, 2020).

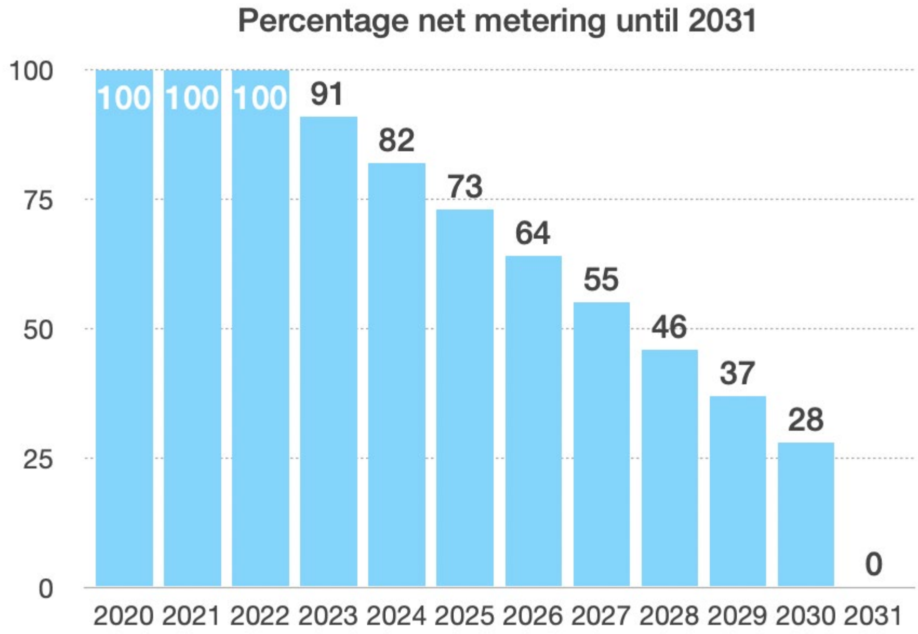

Figure 2: Net metering percentage until 2031 (Zonnefabriek, 2020).

Overall, PV system owners are encouraged to inject less electricity into the grid and to directly consume as much as possible by themselves. In order for this to be possible, apart from investing in storage technologies such as home batteries, homeowners will have to plan their energy consumption to be higher when they generate their own electricity.

2.3 Home Energy Management Systems

HEMS solutions have made their entrance into the market during the past decade but have always been quite expensive without really guaranteeing a relevant return of investment from energy savings. Ultimately, some HEMS companies have made some steps ahead in terms of technological innovation and system integration, showing a huge potential if pictured in the future.

Some of the benefits offered by HEMS are described in the following paragraphs.

2.3.1 Monitoring and comparison of energy usage

Home Energy Management Systems can help homeowners to monitor not only how much energy they are using, but also where and when they are using it. Furthermore, the energy measured can be compared with the energy consumed in the past, or even with energy consumed in other similar households (Smappee, Smappee Infinity, 2020).

The possibility to monitor energy consumption would be a relevant added value for a company like Woon Duurzaam. Indeed, a HEMS can offer useful insights during their first step of operation towards energy optimization, when the energy behaviour of the household is analyzed before proposing a customized energy plan. Furthermore, since Woon Duurzaam's goal is to provide full lifecycle sustainable solutions, the implementation of a HEMS is an add-on for their maintenance proposition, after the retrofit installations are completed.

2.3.2 Control and automation of energy systems and appliances

Especially if installed in households equipped with PV, heat pumps, batteries and EV charging stations, HEMS can help to manage the energy fluxes inside the house from one system to another (Smappee, Smappee Infinity, 2020). A smarter management of internal energy fluxes is essential for homeowners in order to optimize their self-consumption. Actions made possible by HEMS could be, for example, boosting the heat pump when there's a surplus of energy from the PVs, or filling the battery during electricity off-peak hours, when tariffs are cheaper (Geo, 2020).

2.3.3 Circuit breaker protection

If combined with highly consuming loads, like EVs plugged to the house charging point, HEMS can ensure safety of the local network, avoiding overloads and protecting the circuit breaker.

2.3.4 Reduction of household's grid connection capacity

Considering the fee on household electric capacity mentioned in paragraph 2.1, HEMS could be a very important added value to enable households staying below the 3x35A capacity. If unmanaged, a combination of heat pump, an electrical stove and a car charger can bring their grid connection capacity need over 3x25A, significantly adding costs.

2.3.5 Grid Balancing

HEMS constitute a key element of the physical domestic energy infrastructure of smart grids (Smale, van Vliet, & Spaargaren, 2017): a house provided with a home energy management system could become a flexibility provider for the grid. In the Netherlands, householders may in the near future have the opportunity to sign up for a discounted energy contract which includes a flexibility clause, essentially authorizing grid operators to remotely and directly manage demand, for example by fluctuating 'smart' electric boiler temperatures, as well as by controlling appliances such as fridges and washing machines (Schick & Gad, 2015). Such arrangements would generate flexibility without the need for active time-shifting by householders.

2.3.6 Peer-to-peer energy trading

Today, exporting energy to the grid and importing it requires a central administration that keeps track of all the energy traffic (to and from the grid) and that sends each player an invoice, usually once a year or once a month.

However, in a neighbourhood with many houses equipped with PVs and willing to share the surplus of energy with the neighbours, energy trading could be drastically simplified by the use of blockchain technology, avoiding the need for a centralized grid management. Although this scenario is not yet possible in the Netherlands, it may be allowed in the future. Every house would need to have a HEMS and a personalized digital currency account like SolarCoin (SolarCoin, 2020), that keeps track of production and consumption. Blockchain technology would do the rest, allowing users to keep track of consumption and of who owes how much to who.

It is likely that this will be the future scenario of decentralized energy production and consumption, in which there is no longer any need for a centralized grid management or utility which keeps track of consumption. The digital currency would become the energy meter: it keeps track of consumption/production and settles the bill at the same time. Obviously, this scenario is only possible if every house has installed an advanced energy monitor system (Smappee, 2017).

2.4 Batteries

As the energy produced by households through PVs increases, together with the energy consumed by electric cars and heat pumps, there is a need to minimize the peak load on the electricity grid and to distribute the load as much as possible throughout the day. Since under normal circumstances a family's consumption is concentrated in the morning and early evening, home batteries are being increasingly adopted in order to satisfy this need. In presence of flexible rates, households are encouraged to shift their consumption to cheap moments (with low network load) as much as possible (Enexis, 2018). When the price of electricity is low, the battery can be charged, while when the price is high, the battery can be discharged and make profit by selling electricity back to the grid (van der Stelt, AlSkaif, & van Sark, 2018).

The main downside of residential battery exploitation lies in its still not competitive price, being currently around 500 €/kWh (Tesla, 2020) (LG Chem, 2018). Furthermore, in the Netherlands, due to the net metering policy and the convenient feed-in tariff for self-generated electricity, there has been no incentive to invest on home batteries until now (van der Stelt, AlSkaif, & van Sark, 2018).

In the past few years, due to economy of scale gains by the industry and interventions by states and governments, the costs of batteries have declined considerably. Figure 3 shows the trends in battery system costs: it is possible to notice that the price of a Lithium ion battery will be around 350 €/kWh in 2025 and 250 €/kWh in 2030 according to the study. (IRENA, 2019). This, together with the increasing need to maximise electricity self-consumption in houses due to the net metering policy phasing out, will make the Netherlands a fertile ground for the future deployment and commercialisation of battery storage systems.

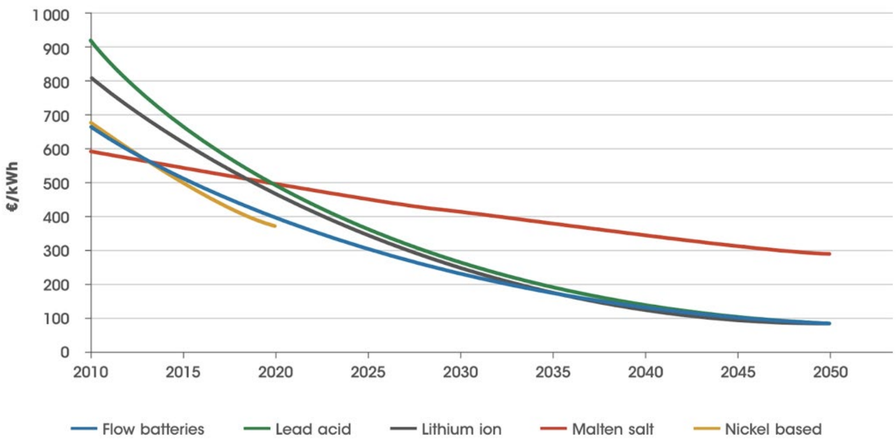

Figure 3: Battery Systems Cost Trends (IRENA, 2019)

2.5 Hybrid Inverters

A hybrid inverter is an inverter which can simultaneously manage inputs from both PV panels and battery, charging batteries with either electricity produced by the solar system or coming from the grid (depending on which is more economical or preferred). Installing a hybrid inverter allows PV and battery owners to make a single investment, instead of buying a PV inverter coupled with a separated battery inverter.

The features allowed by this unit are comparable to the ones offered by a home energy management system, and are the following (Goodwe, 2020):

- **Self-Consumption enhancement**
  Electricity from the PV array is used to optimize self-consumption during the sunlight hours. The excess power charges the batteries and is used to supply the loads at night.
- **Peak Shaving**
  By setting the charging and discharging time according to the time-of-use tariffs, the battery can be charged during off-peak hours, and thus with cheap electricity, and discharged to feed the loads during peak hours
- **Backup**
  Critical loads such as fridges, internet routers, lighting, can be powered when the grid fails.

2.6 Crowd Balancing Examples

Due to EU's energy and climate objectives for 2030, the share of renewables is expected to reach the 50% of the total electricity produced. Renewable energy sources like solar and wind are intermittent, meaning that it is not sure whether the electricity produced can constantly meet the demand, making it difficult to balance the supply and demand of electricity. At the same time, consumers are becoming power generators, mainly through PVs, and the demand for electricity is rapidly increasing, due to the adoption of heat pumps for space heating and domestic hot water, and of electric vehicles as means of transportation. Balancing personal energy demand and production is complicated because of the different periods of the day in which electricity is consumed (in the morning and in the evening) and produced (during periods of maximum solar irradiation, thus around midday). This results, on one side, in a risk of further increasing the peak load on the system, due to a higher needed capacity in the morning and in the evening, on the other side in voltage problems due to the significant amount of energy produced by PVs around midday and fed into the grid because not consumed. Distribution system operators would thus be obliged to increase grid capacity through grid reinforcements, a time consuming and costly solution (USEF Foundation, 2015).

Considering the energy market scenario of the past decades, in which large-scale, centralized power plants were supplying every home and business in a limited area with as much electricity as it wanted, it is immediate to understand that today's markets are not sufficiently flexible to integrate large shares of intermittent renewable energy sources, on either the supply side or the demand side. Fortunately, electricity consuming devices like heat pumps, domestic appliances, electric vehicles and HVAC (Heating, Ventilation and Air Conditioning) systems can offer flexibility by changing their load profile. For example, an electric vehicle could start charging earlier, when there's a significant production of wind or solar power, moving the load profile forward in time. Alternatively, the charging process could be slowed down in case of grid congestion during peak times. The same type of flexibility can be offered by the charging and discharging process of residential batteries, as well as by boosting or reducing the power of the heat pumps, exploiting the thermal buffering of buildings and storage vessels, as well as by shifting the load of the appliances. This is known as demand response (USEF Foundation, 2015).

The flexibility that households' demand-response devices can provide is a blessing to the energy market. In fact, it provides a way to compensate for the intermittence of renewable energy sources, helping all the involved stakeholders: energy producers, Transmission System Operators (TSOs), Distribution System Operators (DSOs), Balance Responsible Parties (BPRs) and energy suppliers. These entities can currently exploit the flexibility obtained from the demand-response resources owned by residential end users in order to reduce peak loads, preventing the dispatch of less efficient generation, and to adapt the consumption profiles to the availability of renewable energy sources such as the wind and sun. Furthermore, a new role is being introduced in the market, the one of the aggregator, which accumulates the flexibility from households (as well as from other end users) in order to create a single entity able to participate in the power market. This pool of flexibility is turned into products to serve the needs of the various stakeholders, resulting in a reward for the household. One advantage of aggregation is that these products provide reliable flexibility to the market by eliminating the risk of non-delivery inherent in depending on an individual prosumer. At the same time, aggregation prevents prosumer exposure to the risks involved in participating in the energy market (USEF Foundation, 2015).

Currently, many research pilots are running in the Netherlands to show the flexibility potential of batteries, heat pumps, and electric vehicles.

A first example is the blockchain project carried out by the Dutch TSO TenneT together with Vandebron Energie B.V., a marketplace provider of renewable energy. Vandebron links 120 small-scale energy producers such as farmers with around 100,000 energy-conscious consumers, among which many are electric vehicles owners. The project consists in drawing power from the Vandebron electrical network to supplement the grid in times of highest demand. Participating Vandebron customers will make the capacity of their car batteries available as distributed energy sources to help TenneT balance the grid. When TenneT needs to increase power in the grid, charging will briefly stop, and the car owner is compensated for the interruption (IBM, 2018).

Another example is Eneco CrowdNett, a Dutch-based aggregator of home batteries that provides grid services through a network of home batteries owned by prosumers. Consumers can purchase batteries at a discounted price and receive a reimbursement of 400-500 € annually for 5 years, depending on the purchased battery, in exchange for access to 30 % of the battery capacity at any time during the day. The shared energy coming from the batteries allows Eneco to keep electricity grid in balance, avoiding the necessity to rely on coal-fired power plants (Eneco, 2020).

3 Research Objectives

The objective of the Thesis is to investigate possible solutions to be proposed to Dutch homeowners in order to prepare for the shift in energy consumption's regulations mentioned in paragraph 2.2. Currently, in the Netherlands, a great number of houses, pushed by favourable regulations and subsidies, have installed PV systems on roofs. As regulations will change from 2023, measures must be proposed to maximize the auto-consumption of the energy produced. Considering the technologies currently or imminently available on the market, these measures will mainly consist of HEMS and battery implementations, to be combined with PV panels and possibly with heat pumps and EVs charging points. Best solutions here considered are the ones able to guarantee the higher savings for the clients, but also to provide the most interesting profit opportunities for Woon Duurzaam.

Another main objective is to propose Woon Duurzaam solutions able to monitor energy production and consumption inside the houses. These products provide a simpler solution compared to the ones considered for the self-consumption maximisation, and are meant to be offered to the clients at a lower price, within the range of 100-300€.

3.1 Monitoring Solutions

Research on monitoring products is focused on solutions able to monitor not only the general electricity consumption, but also to submeter the consumption of heat pumps and the production from PV panels. As a plus, possibility to monitor charge and discharge of EV is evaluated. The main scope of the company by selling these products is to improve their maintenance offer: many problems and malfunctioning of the installations could be in fact solved from distance, with savings from the reduced dedicated time and commuting.

3.2 Self-consumption maximization solutions

The main scope of this part is to analyse the business case in the Netherlands for products able to control household's consumption and production according to weather forecast, demand prediction, and electricity prices. The other objective is to identify the best target for the sale of these products among Woon Duurzaam's different client profiles.

A major part of the thesis work is the research and study of Home Energy Management Systems (HEMS), in order to understand the features currently provided by the commercially available solutions. An explanation of this type of system is shown in paragraph 2.3. Priority is assigned to systems that not only allow to monitor and compare energy consumption, but that can also control the energy fluxes inside the house. Actions made possible by HEMS could be, for example, boosting the heat pump when there's a surplus of energy from the PVs, or filling the battery during electricity off-peak hours, when tariffs are cheaper.

For batteries and hybrid inverters, the focus will be on identifying the best solutions in terms of quality/price ratio, also considering the possibility for Woon Duurzaam to establish profitable partnerships.

3.3 Smart Grid Demand Side Management

Since one of the main reasons for the changes in regulations is to support low-voltage grid management, the solutions proposed in this project could directly or indirectly affect the electricity network and thus perfectly fit into the concept of demand-side flexibility. A situation in which HEMS allow houses to consume more during the off-peak hours, thus providing peak's shaving and deferment, is a favourable situation from the perspective of grid operators. These houses can offer flexibility to the network, and consequently they can be rewarded for this service.

Although the investigation will be mainly focused on the household's side, the possibility will be studied for Woon Duurzaam to partner with Aggregators, DSO or Retailers in order to offer products to homeowners at a reduced price.

4 Methodology

The first stage of the project consists of a research of the available solutions on the market for maximising self-consumption of produced electricity. During and after this phase, and while picturing possible companies to partner with, a techno-economic model is designed based on 2 different scenarios created taking into account different occupancy and heating profiles (household energy profiles). For each scenario, several different configurations have been created, considering the implementation of different solutions for self-consumption maximisation, together with different sizes of the PV system and with or without taking into account the use of an electric vehicle. The total energy bill has been calculated for each case over 15 years, together with the savings and ROI (Return of Investment) compared to the situation without batteries or HEMS (Case 0). Following the results of the Techno-Economic analysis, a market proposition and a sales volume projection has been created for the inclusion of a HEMS solution in the company products portfolio.

4.1 Products Exploration

Solutions for or maximising self-consumption of produced electricity mainly consist of HEMS, batteries and hybrid inverters. The methodology used to identify most suitable options relies on the following parameters:

- Possibility to control energy fluxes, and not only to monitor energy consumption
- Willingness of the company to partner with Woon Duurzaam
- Total cost of the solution
- Maturity of the solution
- Existence of an ecosystem already in the Netherlands (for example, the system has been already installed in many houses and proved to work)

4.2 Scenarios Creation

The most typical Woon Duurzaam client profile has been identified as a family of 4 people, living in a detached or semi-detached house built before the ‘80s and then renovated. Starting from this setup, different configurations have been created, reunited under 2 big groups, Scenario 1 and Scenario 2. Scenario 1 takes into account the occupancy and heating profile of a family, while Scenario 2 considers a couple of seniors.

For each scenario, 3 sub-scenarios have been created:

- **Sub-scenario 1**

  In this sub-scenario, an 8 kW PV system has been considered (PV profile 1 or PVP1), together with a 13.5 kWh battery (Battery profile 1 or BP1)

- **Sub-scenario 2**

  In this sub-scenario, an 8 kW PV system has been considered (PV profile 1), together with a 6 kWh battery (Battery profile 2 or BP2)

- **Sub-scenario 3**

  In this sub-scenario, a 4 kW PV system has been considered (PV profile 2 or PVP2), together with a 6 kWh battery (Battery profile 2 or BP3)

Each sub-scenario has been studied considering 2 different configurations, the first one of a renovated house, the second one of a newly built house, thus with differences in thermal performance. For each configuration, two sub-configurations are created in order to consider or not the impact on the energy consumption derived from charging an EV at home. Details regarding the different considered thermal performance situations and EV charging patterns are included in paragraphs 6.1.1 and 6.1.5.

For each sub-scenario and for each configurations the following different cases have been considered:

Case 0: The house has a PV system and Heat Pump

Case 1: The house has a PV system, Heat Pump, a battery and a HEMS

Case 2: The house has a PV system, Heat Pump, and a HEMS

A scheme of the considered configurations and cases for each scenario is shown in Figure 4.

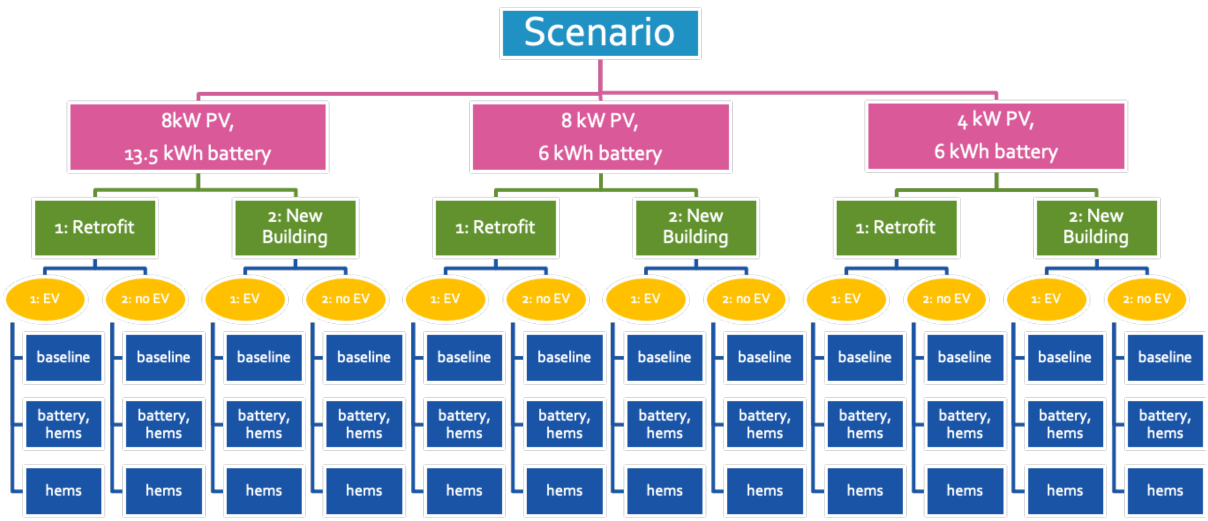

Figure 4: Visualisation of the different considered configurations and cases for each scenario

4.3 MATLAB Model

The hourly electricity consumption for every considered situation over 15 years has been calculated through a MATLAB algorithm. The algorithm simulates the electricity consumption of the heat pump matching the power output and COP (Coefficient of Performance) of the machine with the house heating requirement at every temperature. Other considered consumptions are the ones for air conditioning and EV charging, together with the electricity requirement for running all the appliances. At the same time, the hourly PV production is analysed.

For the situations in which a HEMS together with a battery or just a HEMS is considered (case 1 and 2), features showed in paragraph 6.1.7 are considered.

The consumptions and productions are calculated for every hour of the day.

4.3.1 House Heating Requirement

The heating power required at every temperature has been calculated with the software Vabi Elements (Vabi, 2020). In order to calculate this value, a design of the house has been sketched, using the properties of the materials showed in paragraph 6.1.1 and the room temperature requirements according to the scenarios. The 3D model of the house is included in Appendix A.

4.3.2 Heat Pump Energy Consumption

The energy consumed by the heat pump at every hour has been calculated using the performance datasheet provided by Vaillant (Vaillant, 2020). This publication, included in Appendix A, shows the power output and COP of the machine at every temperature and considering the variations of the compressor's speed. The specifications are shown in Figure A 2.

For every hour of the year, the power output of the heat pump has been selected to match, when possible, the heating requirement of the house, according to the external temperature information found on PVWatts (PVWatts, 2020). The correspondent energy consumption has been calculated with *Equation 1*:

$$hourly\ consumption\ (h) = \frac{heat\ pump\ power\ output\ (T)}{COP\ (T)}\ [kWh] \qquad \text{Equation 1}$$

where the temperature (T) is the temperature related to the specific hour of the day (T=T(h)).

Domestic Hot Water (DHW) consumption has been also included in the hourly consumption. Assuming a consumption of 7 GJ on average in the Netherlands (Miltenburg, 2016), this value has been converted into a daily consumption of 1.8 kWh/day per occupant for Scenario 1 and 1 kWh/day for Scenario 2 (Aguilar, White, & Ryan, 2005), as explained in paragraph 6.1.1. The daily consumption has been converted in hourly consumption, assuming that the need of DHW is from 7 to 9 in the morning and from 18 to 22 in the evening.

The energy content in the buffer has been calculated assuming a temperature of the water in the buffer of 65°C and supplied to the system at 35°C. With a water's specific heat (c) of 4.186 kJ/kgK, the formula used to calculate it is Equation 2:

$$energy\ buffer = \frac{c * \Delta T * size\ buffer}{3600}[kWh] \qquad \text{Equation 2}$$

Where the size of the buffer is 40 l.

During the hours in which the external temperature is very cold and, therefore, the thermodynamic cycle of the heat pump can't supply enough heat to meet the thermal requirement of the house, the extra heating is provided by the electric element inside the unit. It is assumed that the electric element has an efficiency of 90%. The resulting consumption is given by Equation 3:

$$hourly\ consumption\ (h) = \frac{heat\ pump\ power\ output\ (T)}{COP\ (T)} + \frac{integrative\ power}{\eta_{electric\ element}}\ [kWh] \qquad \text{Equation 3}$$

If the minimum power that the heat pump can supply is higher than the house requirement, the extra power is used to fill the buffer. Then, if the minimum power is still higher than the demand, the unit is switched off.

4.3.3 Battery Charging and Discharging

The battery is charged with the surplus of solar power and, when a HEMS is considered, with electricity from the grid during low-price hours. When the surplus of solar power is higher than the maximum battery charge power (ex. 5 kW for the Tesla Powerwall 2), the extra power is injected into the grid. At the same time, the battery is discharged when there's a demand from the house and, if a HEMS is considered, during high-price electricity periods.

4.3.4 Electricity Bill

In order to calculate the electricity bill, the net metering formula has been considered, as described in paragraph 2.2.2. Thus, hourly electricity fed into the grid and subjected to net metering is calculated with Equation 4:

$$feed\ net(h) = feed(h) * (1 - 0.09 * year)\ [kWh] \qquad \textit{Equation 4}$$

Where feed(h) is the hourly amount of electricity fed back to the grid (produced by the PV panels and not directly consumed), one of the outputs of the MATLAB model. The second factor of the multiplication, $(1 - 0.09 * year)$, considers the annual 9% reduction in the amount of electricity fed back to the grid and subjected to net metering. Year is a number which varies from 1 to 10, according to the changes in Net metering percentage showed in Figure 2.

The hourly electricity fed into the grid and not subjected to net metering is calculated with Equation 5:

$$feed\ nonet(h) = feed(h) * 0.09 * year\ [kWh] \qquad \textit{Equation 5}$$

with the year varying between 1 and 8, from 2023 to 2030.

After 2030, all electricity fed into the grid is considered as not subjected to net metering.

The hourly electricity bill is calculated with Equation 6:

$$\begin{aligned} bill(h) = {} & (grid\ consumption(h) - feed\ net(h)) * tariff(h) * increment \\ & - feed\ nonet(h) * 0.8 * delivery\ price \end{aligned} \qquad \textit{Equation 6}$$

Where the increment is the expected annual increase in electricity price (4%) and the grid consumption is given by Equation 7:

$$\begin{aligned} & grid\ consumption(h) \\ & \quad = consumption\ heat\ pump(h) + consumption\ aircon(h) \\ & \quad + consumption\ EV(h) + consumption\ appliances(h) \\ & \quad - PV\ production\ (h) - battery\ discharge(h) + battery\ charge(h) \end{aligned} \qquad \textit{Equation 7}$$

The tariffs and the delivery price are described in paragraph 6.1.9.

4.3.5 Savings, Return of Investment, and Payback Time calculation

For every specific configuration, savings over 15 years are calculated by comparing the electricity bill of each case with the one of case 0, in which no smart technologies are included. The cost of the solution is not included in the savings calculation but is considered when analysing the Return of Investment (ROI) and the Payback Time PBT.

ROI has been calculated with Equation 8:

$$ROI = \frac{savings - cost\ of\ the\ solution}{cost\ of\ the\ solution} \qquad \text{Equation 8}$$

Where savings are the savings on electricity bill over 15 years.

PBT has been evaluated considering when the accumulated savings, shown in Appendix D, reached the cost of the equipment.

Cost of each solution are included in Appendix B, with specifications of each considered technology explained in Chapter 5. The lifetime period of the technologies has been conservatively assumed to be 15 years.

5 Products Exploration

Following the scopes of the project, several products have been investigated, mainly focusing on mature solutions already available on the market, but also considering technologies not yet fully deployed, that will be market ready in the coming future.

Parameters taken into account while performing the market exploration are:

For the products

- Product maturity
- Product development potential
- Cost of the product

For the companies

- Company position in the market
- Possibility of "growing together"

In the following paragraphs, explored solutions are described in detail, for the two proposals of the project: Energy Monitoring and Self-consumption maximisation.

5.1 Monitoring Products

Products investigated for the monitoring proposal are listed below. Information about single components and prices are included in Appendix B.

- **IUNGO**
  Monitoring of household general consumption, appliances (through smart plugs), PV production, heat pump, EV charger, as well as CO_2, humidity, and water consumption. The data collected can be monitored by both the homeowner and the builder, in this case Woon Duurzaam (IUNGO, 2020).

- **CEMM**
  Available in 2 different configurations. The simplest version, CEMM basic, monitors PV production and heat pump consumption. The advanced version, CEMM plus, monitors PV production, heat pump consumption and EV charger (CEMM, 2020).

- **ENELOGIC YOULESS**
  It reads the smart meter through the P1 port and it's coupled with an energy meter. It can monitor the production of PV panels, electric cars and heat pump, together with the general household consumption (Enelogic, 2020).

- **HOMEWIZARD**
  It's a P1 smart meter reader connected with an energy meter. The functions are similar to the one of the Enelogic Youless (HomeWizard, 2020).

5.2 Self-consumption maximization Products

Products investigated for the self-consumption maximisation proposal are home energy managers, also known as home energy management systems (HEMS), home batteries, and hybrid inverters.

5.2.1 HEMS

- **Smappee**
  Smappee Infinity is a modular system composed of a power box, a gateway and several clamps (CT hubs, or Current Transformer hubs). Consumption of singular appliances can be sub-metered and monitored through the clamps in the breaker panel. This also includes the consumption of the heat pump, electric vehicle, and the solar production of the PV system. In particular, the system implements a smart EV charging function, which enables overload protection and dynamic load balancing with optimized self-consumption, based on forecast of energy production and consumption, price of electricity and user's needs (ex. EV charging schedule). Automation rules in the energy fluxes management from the PV system are also possible with other appliances: for example, it is possible to reduce or boost the current going to the water heater during peak or off-peak hours. In the future, the automation rules will be extended and fully integrated to heat pumps and batteries, that are currently only monitored (Vermeulen, 2020).

- **Geo**
  Hybrid Home is Geo's home energy system, built around *Core,* the company home energy management system. The solution is an all-in-one system, which includes the HEMS and the storage technology. It is currently not yet available on the market, and trials are under development in the UK and Norway (Hughes, 2020).
  Core features automation functions based on learning, predicting and optimizing the consumption and production patterns of the house, maximising house self-consumption by the scheduling and switching of DSR-ready (Demand Side Response Ready) appliances. The automation is made possible by an algorithm that predicts demand and generation of energy, as well as cost of electricity. Appliances, heat pumps and EV charging are controlled accordingly, and the artificial intelligence optimises schedules to meet household preferences, be that lowest cost, greatest convenience, or greenest energy. Furthermore, the system can help balancing the electricity grid by responding to aggregator signals to deliver flexibility services (Geo, 2019).

- **SMA**
  SMA Energy Systems Home is the integrated solution proposed by SMA for generating, storing and managing energy production from PV panels. The intelligent management of the energy inside the house is made possible by the *SMA Sunny Home Manager 2.0*®. On the basis of an online weather forecast and of the household consumption analysis, the system creates a day-by-day yield forecast, in order to know in advance when a surplus of solar power will be available and when is the right time to start the appliances and to boost or reduce the power of the heat pump. The energy manager is able to control appliances, heat pumps, hot water tanks, as well as charging and discharging the home battery according to the forecast of solar production, demand, and cost of electricity (SMA, 2020).
  The advantage of the system is the fully supported compatibility with SMA inverters, as well as with products from other brands, including heat pumps, air conditioners, hot water tanks, wet

appliances and charging station (SMA, 2020). The communication is guaranteed by the EEBUS standard.

- **Solarwatt**
  Solarwatt *EneryManager's* functions are similar to the ones offered by the SMA solution. The *EnergyManager* collects information from the solar panels, inverters, batteries, and other components of the photovoltaic system, measuring at the same time the power consumption of the devices via the circuit or with the aid of smart sockets. The software in the *EnergyManager* then optimizes the whole home's power consumption, ensuring that devices are switched on and off at the right time. The customer can adjust his personal energy management at any time, for example setting when each appliance is to be turned on or off individually. Otherwise, it is possible to let the system doing everything automatically, allowing the self-learning software to react to the daily energy usage switching appliances on and off at the optimal time (SOLARWATT, 2020).

The price of the solutions is included in Appendix B. Due to the maturity of the product, the reliability of the company and the possibility to receive useful insights from Woon Duurzaam's partner Zonnefabriek, the SMA Sunny Home Manager 2.0® has been selected as the most complete solution for the company to focus on. Therefore, assumptions and calculation in Chapter 6 are made according to the specifications of this product.

5.2.2 Batteries

For the scope of the project, two main battery size ranges have been explored: 12.5-14 kWh and 5-6 kWh. These two different sizes have been implemented in the techno-economic model and analysed. Prices and specifications of the considered products are showed in Table 2.

For the biggest size typology, Tesla, LG Chem and BYD solutions can rely on a competitive and similar price/kWh. However, the advantage of the Tesla Powerwall 2.0 is the integrated inverter, which allows the costumer to avoid an extra investment: instead of coupling the PV system with a PV inverter and a battery inverter, only the PV inverter will be needed. Therefore, Tesla's product is considered for further calculations in this research.

For the smallest battery size typology, the solution offered by LG Chem has been considered as the best one and further analysed. The downside of the Solax battery, indeed, is its incompatibility with inverters coming from other brands than Solax. This undermine considerably its potential in retrofit configurations.

Table 2: Batteries Specifications

Product	Usable Energy (kWh)	DOD	Charge/Discharge Power (kW)	Price/kWh (€/kWh)	Source
Tesla Powerwall 2.0	13.5	96.4%	5 (steady) 7 (peak)	496	(Tesla, 2020)
LG Chem RESU 13	12.4	95%	5	~510	(LG Chem, 2018)
BYD B box Pro 13.8	13.8	100%	12.8	~510	(Europe-SolarStore.com, 2020)
All-in-One Soltaro 5kW / 13.5 kWh	12.15	90%	5 (steady) 15.5 (peak)	~750 (estimated)	(Europe-SolarStore.com, 2020)
LG Chem RESU 6.5	5.9	90.7%	4.2	~650	(LG Chem, 2018)
Solax Triple Power T63	5.7	90%	2.5	~625	(Europe-SolarStore.com, 2020)

5.2.3 Hybrid Inverters

As mentioned in Paragraph 2.5, hybrid inverters have similar functions to the ones of home energy management systems. These solutions can offer (Goodwe, 2020):

- **Self-Consumption enhancement**
  Thanks to weather forecast and consumption prediction, electricity from the PV array is used to optimize self-consumption during the sunlight hours. The excess power charges the battery and is used to supply the loads at night. Devices can be controlled, and their operation prioritized according to the data communicated by the production and consumption forecast applications.

- **Peak Shaving**
  By setting the charging and discharging time according to the time-of-use tariffs, the battery can be charged during off-peak hours, and thus with cheap electricity, and discharged to feed the loads during peak hours. Also, the peak power drawn from the public distribution network can be limited, allowing a subscription to a power which is lower than the one is required.

- **Backup**
  Critical loads such as fridges, internet routers, lighting, can be powered when the grid fails.

Solutions proposed by Imeon, Fronius, Kostal and Goodwe have been explored. Due to lack of response from the companies, and impossibility to get insights from Woon Duurzaam partners regarding the technology, Hybrid inverters have not been considered in the Techno-economic model.

6 Techno-Economic Model

The techno-economic model is the core of the project. A research has been conducted in order to define a typical Woon Duurzaam client profile. Information of each customer has been collected and a most typical profile has been identified, as shown in Table 3.

Table 3: Typical Woon Duurzaam client profile

House and residents' information		**House Energy performance**	
House typology	Detached	Heating Requirement at -5°C (kW)	8.3
Year of construction	1975	Electricity Consumption (kWh/y)	10900
Volume (m^3)	500	General Electricity consumption (kWh/y)	5000
Number of residents	4	Electricity Production (kWh/y)	6600
Age and Profile	2 adults and 2 kids	Net Energy Consumption (kWh/y)	4300

It is possible to observe that the typical Woon Duurzaam client is identified as a family of 4 people, living in a detached or semi-detached house built before the '80s and then renovated. This situation has been encountered in 20 cases out of the 31 analysed, representing the 65% of clients. This set-up has been therefore taken as a starting point for the creation of different configurations, reunited under 2 big groups, scenario 1 and scenario 2. A sensibility analysis is made in order to study the change of performance in function of the following variables:

- **House thermal performance**
  For each scenario, savings are calculated with an old and then renovated house, as the one pictured in the typical Woon Duurzaam Profile, and with a newly built house. Information regarding the different thermal performances are included in Paragraph 6.1.1.
- **N° of residents**
  A house of 4 people has been considered in Scenario 1, while 2 occupants were considered in Scenario 2.
- **Residents profile and occupancy**
  - Scenario 1: Adults + kids
  - Scenario 2: Retired
- **Presence of Electric Vehicle**
- **PV system size**
  A 7.6 kW and 4 kW DC system sizes are compared
- **Battery system size**
  Batteries of 13.5 kWh and 6 kWh are compared

The two analysed scenarios are developed according to the characteristics of the typical Woon Duurzaam client profile. Scenario 1 considers a family (2 adults and 2 kids), while scenario 2 considers a retired couple (2 seniors).

In order to perform the sensibility analysis, 2 different configurations have been created for each Scenario, the first one of a renovated house, the second one of a newly built house, thus with differences in thermal performance. For each configuration, two sub-configurations are created in order to consider or not the impact on the energy consumption derived from charging an EV at home. For each scenario and for each configurations the following different cases have been considered:

Case 0: The house has a PV system and Heat Pump

Case 1: The house has a PV system, Heat Pump, a battery and a HEMS

Case 2: The house has a PV system, Heat Pump, and a HEMS

6.1 General Assumptions

6.1.1 House Thermal Performance

The Building Decree ("Bouwbesluit") states a minimum thermal performance requirement for new and renovated dwellings, prescribing a Rc value of at least 3.5 m^2 K/W for the building envelope and a U value of 1.65 W/m^2 K for windows, doors, and other transparent surfaces. Furthermore, for new buildings, an EPC (Energie Prestatie Coëfficiënt) value of 0.4 or less is required (EPC, 2020), with minimum building requirements from the decree listed in Table 4.

Table 4: EPC 0.4 minimum Rc and U value requirements

EPC minimum requirement		
House part	RC-value (m^2K/W)	U-value (W/m^2K)
Floor	≥3.5	
External Walls	≥4.5	
Roof	≥6	
Windows		≤1.65

Both scenario 1 and scenario 2 have been studied in 2 different house configurations, assuming for the first configuration that the house is built before 1980 and then retrofitted, for the second configuration that the house is a new construction, more ambitious compared to the EPC requirement of 0.4. The properties of the house envelope in the 2 configurations are shown in Table 5.

Table 5: Rc and U value for the two studied thermal performance configurations

	House Properties - Retrofit Heating Requirement at -5°C: 8,3 kW		**House Properties - New Construction Heating Requirement at -5°C: 4,2 kW**	
House part	RC-value (m^2K/W)	U-value (W/m^2K)	RC-value (m^2K/W)	U-value (W/m^2K)
Floor	4.3		4.3	
External Walls	4		4.5	
Roof	4.3		6	
Windows		1.1		0.8

The heating requirement for both the configurations have been obtained performing a heat loss simulation with the Vabi Elements software (Vabi, 2020).

Milieu Centraal estimates an annual Domestic Hot Water consumption of 7 GJ on average in the Netherlands (Miltenburg, 2016). This value has been considered in the MATLAB model, converted into a daily consumption of 1.8 kWh/day per occupant (Scenario 1). For Scenario 2, it has been considered that on average seniors consume 44% less water per person compared to a family, thus a daily consumption of 1 kWh/day per occupant has been selected (Aguilar, White, & Ryan, 2005).

6.1.2 Heat Pump

In the majority of Woon Duurzaam's renovations, heating and domestic hot water are supplied by an air/water heat pump. The model considered in this case are Vaillant Arotherm Plus 7.5 (for configuration 1) and 5.5 (for configuration 2). Full specifications are included in Appendix A, and a brief comparison is displayed in Table 6.

Table 6: Heat Pump units comparison

	Heat Pump Specifications	
	Configuration 1	Configuration 2
Nominal Power (kW)	7.5	5.5
Average COP	4.5	4.3
Buffer size (l)	40	40

6.1.3 Air Conditioning

Even though the considered heat pump units could provide cooling in summer, it has been assumed for simplicity that comfort during the warm season is provided by air conditioners. The demand for air conditioning is constantly increasing in the past years, reaching an increasing trend of around 300% (Pieters, 2019). The unit considered in this study is a Daiking Prefera C/FTXM + RXM 42N + 42N9 (Daikin, 2020). As a control strategy, it has been considered that the unit is switching on when the external temperature is above 22°C. Specifications are included in Table 7.

Table 7: Air conditioner specifications

Air Conditioner specifications	
Nominal Power (kW)	0.98
Annual consumption (kWh)	178
Assumed hourly consumption (kWh)	0.62

6.1.4 PV System

A simulation of the hourly PV system yield for an entire year has been made through the PVWatts calculator (PVWatts, 2020). Two profiles have been considered:

- **PV Profile 1:** 8 kW DC system size, corresponding approximately to 24 PVs of 320 Wp
- **PV Profile 2:** 4 kW DC system size, corresponding approximately to 12 PVs of 320 Wp

Table C 1 in Appendix C shows the assumption made for the system.

6.1.5 EV Charge

For the EV charging calculations, the autonomy and load capacity of a Nissan LEAF® has been considered, being one of the most adopted electric cars on the market.

An EVBox® 1 phase 16 A charger has been considered for the charge, with a load capacity of 3.7 kW.

For scenario 1, it has been assumed that the car travels a distance of 60 km/day, therefore consuming on average 10 kWh/day. For scenario 2, the considered distance has been reduced to 10 km/day, resulting in an average consumption of 1.7 kWh/day. This assumption has been done considering the difference lifestyle of retired people in comparison with the one of a family.

The calculation has been done according to the declared car's autonomy of 240 km and battery capacity of 40 kWh, resulting in an autonomy per kWh of 6 km/kWh. Thus, the daily recharge will be around 2,7 hours for Scenario 1 and 0,4 hours for Scenario 2. The recharge time has been chosen to take place after midnight.

Table C 2 and Table C 3 in Appendix C shows the characteristic of the considered EV charging system (EVBOX, 2020).

6.1.6 Battery

Two different battery profiles have been considered. Battery Profile 1 is selected in combination with PV Profile 1 (8 kW DC System Size), Battery Profile 2 is selected in combination with both PV Profile 1 and PV Profile 2 (4 kW DC System Size):

- **Battery Profile 1:** 14 kWh Tesla Powerwall 2® (Tesla, 2020)
- **Battery Profile 2:** 6.5 kWh LG Chem RESU65® (LG Chem, 2018)

Table 8: Battery properties and assumptions

	Battery Specifications	
	Battery Profile 1 Tesla Powerwall 2®	**Battery Profile 2** LG Chem RESU65®
Total Energy	14 kWh	6.5 kWh
Usable Energy	13.5 kWh	5.9 kWh
DOD	96.4%	90.7%
Charge/Discharge Power	5 kW	4.2 kW

6.1.7 HEMS

HEMS assumptions have been made taking as a reference the Sunny Home Manager 2.0® by SMA (SMA, 2020). It has been assumed that the HEMS operation is based on a forecast of the PV production and household's consumption for each day. If the forecast for the next day is of a surplus of produced electricity from the PV system, the HEMS performs the following main activities:

- When there's nobody at home, it decreases the Heat Pump compressor's speed during the hours of low solar production, boosting it when the PV generation is on its peak.
- It stores the excess solar power for of thermal storage, turning on the element of the hot water tank in proportion to the amount of power coming out of the panels.
- It shifts the dishwasher and washing machine cycles and starts them during the PV generation's peak hours.

Another important feature of the HEMS is the possibility to address energy fluxes to and from the battery and the grid according to the electricity prices. If the system forecasts that on the day ahead the battery won't be filled with energy coming from the sun, the battery is charged during night, when electricity tariffs are lower. Otherwise, if the solar production for the day ahead is enough to charge the battery, it will be charged with the sun. This feature allows to charge the battery in the most convenient timeslots of the day, either with cheap electricity from the grid or with free electricity from the PV system. At the same time, it minimizes the injection of electricity into the grid due to surplus of solar production.

6.1.8 Occupancy and heating profiles

The main differences between the Scenario 1 and Scenario 2 are the different occupancy profile of the residents, and the different heating profiles.

The occupancy and heating profiles for the 2 scenarios have been considered taking as a reference the study carried out by Guerra-Satin and Silvester (Guerra Satin & Silvester, 2017) of the Dutch occupancy and heating patterns. The findings of the study over occupancy and heating patterns are shown in Appendix C (Table C 4 and Table C 5). The 7 different types of residents are: 1 senior, 1 adult, 2 adults, 2 seniors, 3 adults, single parent and nuclear, where nuclear is considered as a family of 2 adults and 2 or more kids, and single parent is considered as a family of 1 adult and 2 or more kids.

6.1.9 Electricity tariffs

As described in paragraph 2.1, the current price of electricity is the combination of three different components: delivery rate (Leveringstarief), energy tax (Energiebelasting) and ODE. The price of electricity for the H1 2020 is around 0.24 €/kWh (van Dijk, Discussion about electricity prices evolution in the Netherlands, 2020).

Three different tariffs' profiles have been considered in the MATLAB model, explained below and shown in the Figure 5 and Table 9:

1. **Tariff regime 1 (TR1)**:

   Flat tariff of 0.24 €/kWh, without distinction according to the hour of the day or weekends.

2. **Tariff regime 2 (TR2):**

   Off-peak tariff from Monday to Friday from 23:00 – 07:00 a.m. and in the weekend from Friday 23:00 p.m. until Monday 07:00 a.m. (MAINEnergie, 2020). Normal tariff during the other hours of the weekdays. This tariff concept has been created having as a reference MAINEnergie electricity rates, adjusted in order for the average daily tariff to be around 0.24 €/kWh. The tariff scheme can be seen in Figure 5.

3. **Tariff regime 3 (TR3):**

   Time-based tariff based on the day-ahead price variation, multiplied by a factor in order to make the average price close to 0.24 €/kWh. This tariff concept has been created on the base of a pilot project of the DSO Enexis, together with the energy retailer Greenchoice and the project developer Heja. The goal of the pilot was to test dynamic retail, distribution, and local production pricing for household consumers in an apartment block and group of semi-detached houses in Breda (Eid, Koliou, Valles, Reneses, & Hakvoort, 2016).

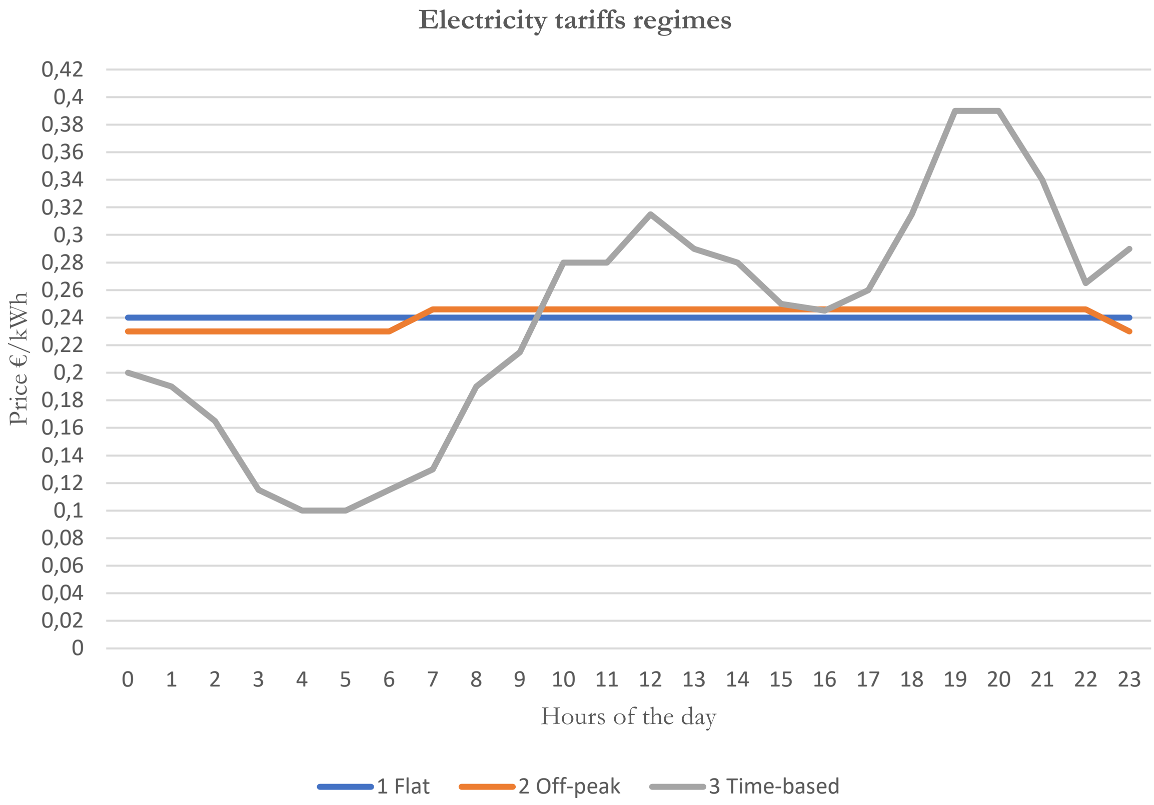

Figure 5: Electricity Tariff regimes, weekdays (MAINEnergie, 2020) (Eid, Koliou, Valles, Reneses, Hakvoort, 2016).

As shown in Figure 5, differences between regimes 1 and 2 are quite limited. These are the conservative profiles, considered because currently most of electricity contracts in the Netherlands adopt flat or double rates tariffs schemes. Regime 3 has been as well considered, following the belief that dynamic tariffs or time-of-use tariffs will be increasingly adopted in the future, due to their benefits for demand-side flexibility. Tariffs that vary in time incentivise load adjustment, allowing customers to save on energy expenses while benefitting the system (IRENA, TIME-OF-USE TARIFFS, 2019). Currently, a bunch of retailers are offering time-of-use or dynamic tariffs contracts, examples are easyEnergy and Mijndomein (easyEnergy, 2020) (Mijndomein, 2020).

Table 9: Electricity tariffs scenarios, weekdays and weekend

	Monday-Friday				Weekend		
h	TR1 €/kWh	TR2 €/kWh	TR3 €/kWh	h	TR1 €/kWh	TR2 €/kWh	TR3 €/kWh
0	0,24	0,23	0,2	0	0,24	0,23	0,23
1	0,24	0,23	0,19	1	0,24	0,23	0,23
2	0,24	0,23	0,165	2	0,24	0,23	0,23
3	0,24	0,23	0,115	3	0,24	0,23	0,23
4	0,24	0,23	0,1	4	0,24	0,23	0,23
5	0,24	0,23	0,1	5	0,24	0,23	0,23
6	0,24	0,23	0,115	6	0,24	0,23	0,23
7	0,24	0,246	0,13	7	0,24	0,23	0,23
8	0,24	0,246	0,19	8	0,24	0,23	0,23
9	0,24	0,246	0,215	9	0,24	0,23	0,23
10	0,24	0,246	0,28	10	0,24	0,23	0,23
11	0,24	0,246	0,28	11	0,24	0,23	0,23
12	0,24	0,246	0,315	12	0,24	0,23	0,23
13	0,24	0,246	0,29	13	0,24	0,23	0,23
14	0,24	0,246	0,28	14	0,24	0,23	0,23
15	0,24	0,246	0,25	15	0,24	0,23	0,23
16	0,24	0,246	0,245	16	0,24	0,23	0,23
17	0,24	0,246	0,26	17	0,24	0,23	0,23
18	0,24	0,246	0,315	18	0,24	0,23	0,23
19	0,24	0,246	0,39	19	0,24	0,23	0,23
20	0,24	0,246	0,39	20	0,24	0,23	0,23
21	0,24	0,246	0,34	21	0,24	0,23	0,23
22	0,24	0,246	0,265	22	0,24	0,23	0,23
23	0,24	0,23	0,29	23	0,24	0,23	0,23

Since the savings calculation is done considering a timeframe of 15 years from 2023, a 4% increase rate has been applied for every year, following the trend of electricity prices between 1995-2005. (van Dijk, Discussion about electricity prices evolution in the Netherlands, 2020).

6.2 Scenario 1

In Scenario 1, the occupancy profile is represented by a family composed of 2 adults and 2 kids/young people. As mentioned in the introduction of Chapter 6, a family with kids is the most common client for Woon Duurzaam. Occupancy patterns have been designed following the guidance of Guerra Satin and Silvester (Guerra Satin & Silvester, 2017), with some adjustments. For instance, it has been assumed that each adult stays at home one day per week, weekend excluded, while the kids are outside home from 8:00 until 16:00 every weekday. The days in which one adult stays at home are Monday and Wednesday.

6.2.1 Appliances Pattern

Appliances pattern is developed according to the occupancy profile. It has been considered an adoption of highly efficient appliances (highest energy label depending on the type of unit) and LED low energy light bulbs. Table D 1 in Appendix D shows the power rating and usage pattern of the considered appliances.

6.2.2 Heating Pattern

The heating pattern has been divided into 4 different settings: At home, Not at home, Half at Home and Night. Each of these settings involves different temperatures for each room of the house, created having as a reference the work of (Guerra Satin & Silvester, 2017). Values for each room are shown in Table 10.

Table 10: Rooms temperature for each heating setting, Scenario 1

Room	T °C (At home)	T °C (Not at home)	T °C (Half at home)	T °C (Night)
Living Room	20	16	19	18
Kitchen	20	16	19	18
Bedrooms	20	16	19	18
Bathrooms	22	16	18	18
Toilets	18	16	16	18
Working Rooms	20	16	19	18
Circulation areas	18	16	19	18
Storage Room	15	15	15	18

The day has been divided in 5 timeslots, and a heating setting has been assigned for each timeslot. As shown in Table 11, the setting "Half at home" appears on Monday and Wednesday, days in which 1 adult stays at home. Regarding the weekend, it has been assumed that the family is out on Saturday for a great part of the day, while it stays at home on Sunday. The heat pump is on at night only in December, January and February. From May to September, it only provides Domestic Hot Water. The choice of keeping the heat pump working at night during the coldest months has been made for thermal comfort reasons, as well as to reduce the peak of demand in the morning. The possibility to include heating at night in order to reduce morning peak of demand also in the other months has been considered but not included in the model. The main reason is that heat pump performance is lower at night due to colder temperatures, other issue is represented by the noise problem, usually raised by clients. Also, considering the very good level of insulation provided in the renovations, there are usually no cold complaints due to the heating kept off at night during mid-seasons.

Table 11: Heating pattern for Scenario 1

	Time of the day				
Day	0-6	7-9	10-17	18-22	23-0
Monday, Wednesday	Night	At home	Half at home	At home	Night
Other Weekdays	Night	At home	Not at home	At home	Night
Saturday	Night	At home	Not at home	Not at home	Night
Sunday	Night	At home	At home	At home	Night

6.2.3 Savings Calculation

For the savings calculation, the 3 sub-scenarios mentioned in Paragraph 4.2 have been considered. In particular, the chosen terminology is Scenario 1.1, Scenario 1.2 and Scenario 1.3 as a reference for the 3 sub-scenarios for Scenario 1. They are described as it follows:

1. **Scenario 1.1**
   In this sub-scenario, an 8 kW PV system has been considered (PV profile 1), together with a 13.5 kWh battery (Battery profile 1)

2. **Scenario 1.2**
   In this sub-scenario, an 8 kW PV system has been considered (PV profile 1), together with a 6 kWh battery (Battery profile 2)

3. **Scenario 1.3**
   In this sub-scenario, a 4 kW PV system has been considered (PV profile 2), together with a 6 kWh battery (Battery profile 2)

For each sub-scenario, 2 different configurations have been created: the first configuration considers a dwelling built before the 1980 and recently renovated, with a heating requirement at -5°C of 8.3 kW, the second configuration considers a new building, with a heating requirement at -5°C of 4.2 kW. For each configuration, there are 2 different sub-configurations: one considering an Electric Vehicle, the other not considering it. For each sub-configuration, the savings are calculated in the 3 different cases, as shown in the tables below. The savings are calculated comparing the total final electricity bill with the one of the Case 0, in which no battery or HEMS is considered. Savings for each case are calculated in the 3 tariffs regimes and displayed in Table 12, Table 13, and Table 14. The electricity bill for each case, from which the savings have been calculated, are included in Appendix D (Table D 2, Table D 3, and Table D 4). The cost of the equipment is not included here, and considered in the Return of Investment and Payback Time calculations.

6.2.3.1 Scenario 1.1

Savings for Scenario 1.1 are shown in Table 12.

Table 12: Savings Scenario 1.1

		Scenario 1.1 – PVP1, BP1					
		Savings over 15 years €					
		Configuration 1: Retrofit			Configuration 2: New building		
Sub-configuration 1: EV							
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	ev, battery, hems	9579	9713	14112	9938	9815	13373
2	ev, hems	2619	3240	3428	2283	2525	2547
		Sub-configuration 2: no EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	battery, hems	8795	9006	14045	9134	9124	12970
2	hems	2527	3170	3360	2196	2439	2479

As a general pattern, it is possible to notice the follow:

- For **Case 1** (battery + HEMS)
  - Savings are slightly higher when considering a retrofit configuration, here named C1 (Configuration 1).
  - No substantial differences are identified between a sub-configuration with EV or without EV.
  - Savings are between 30% and 40% higher with a type 3 Tariff regime (TR3) compared to the other tariff regimes.
- For **Case 2** (HEMS)
  - Savings are higher in a retrofit configuration (C1) compared to a new building configuration, here named C2 (Configuration 2).
  - Savings are 20-30% higher with a type 3 and 2 Tariff regimes (TR3 and TR2) compared to a flat tariff regime (TR1), when considering a configuration with EV.

6.2.3.2 Scenario 1.2

Savings for Scenario 1.2 are shown in Table 13.

Table 13: Savings Scenario 1.2

		Scenario 1.2 – PVP1, BP2					
		Savings over 15 years €					
		Configuration 1: Retrofit			Configuration 2: New building		
Sub-configuration 1: EV							
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	ev, battery, hems	6532	6617	9489	6587	6542	9348
2	ev, hems	2619	3240	3428	2283	2525	2547
		Sub-configuration 2: no EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	battery, hems	6440	7214	9422	6494	6452	9280
2	hems	2527	3859	3360	2196	2439	2479

As a general pattern, it is possible to notice the follow:

- For **Case 1** (battery + HEMS)
  - No substantial difference is identified between a retrofit and a new building configuration.
  - No substantial difference is identified between a sub-configuration with and without EV.
  - Savings are 40% higher with a type 3 Tariff regime (TR3) compared to the other configurations.
- For **Case 2** (HEMS)
  - Same as Scenario 1.1

6.2.3.3 Scenario 1.3

Savings for Scenario 1.2 are shown in Table 14.

Table 14: Savings Scenario 1.3

		Scenario 1.3 – PVP2, BP2					
		Savings over 15 years €					
		Configuration 1: Retrofit			Configuration 2: New building		
Sub-configuration 1: EV							
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	ev, battery, hems	4500	4810	7837	4656	4788	7701
2	ev, hems	2034	2853	2983	1800	2134	2088
		Sub-configuration 2: no EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	battery, hems	4408	4715	7769	4564	4697	7634
2	hems	1942	2767	2915	1708	2048	2021

As a general pattern, it is possible to notice the follow:

- For **Case 1** (battery + HEMS)
  - Savings are higher when considering a retrofit configuration with EV.
  - Savings are 60% higher with a type 3 Tariff regime (TR3).
- For **Case 2** (HEMS)
  - Savings are higher in a retrofit configuration (C1) compared to a new building configuration (C2)
  - Savings are 40-50% higher with a type 3 and 2 Tariff regimes (TR3 and TR2) compared to a flat tariff regime (TR1), when considering a configuration with EV.

Figure 6 and Figure 7 offer a graphical comparison for the 2 cases in the 4 configurations and sub-scenarios. Scenario 1.2 is not considered for case 2 because equal to scenario 1.1, since only the PV size is considered and not the battery size.

As a general overview, for Case 1, it is possible to notice the decreasing trend of the savings from Scenario 1.1 to Scenario 1.3, with savings in TR3 generally 30-60% higher compared to the other tariff regimes

For Case 2, savings are slightly lower in Scenario 1.3 compared to Scenario 1.1 and Scenario 1.2. It is possible to notice that savings are higher in a retrofit configuration compared to a new building configuration. This is due to the fact that HEMS are mainly influencing the heating consumption of the house.

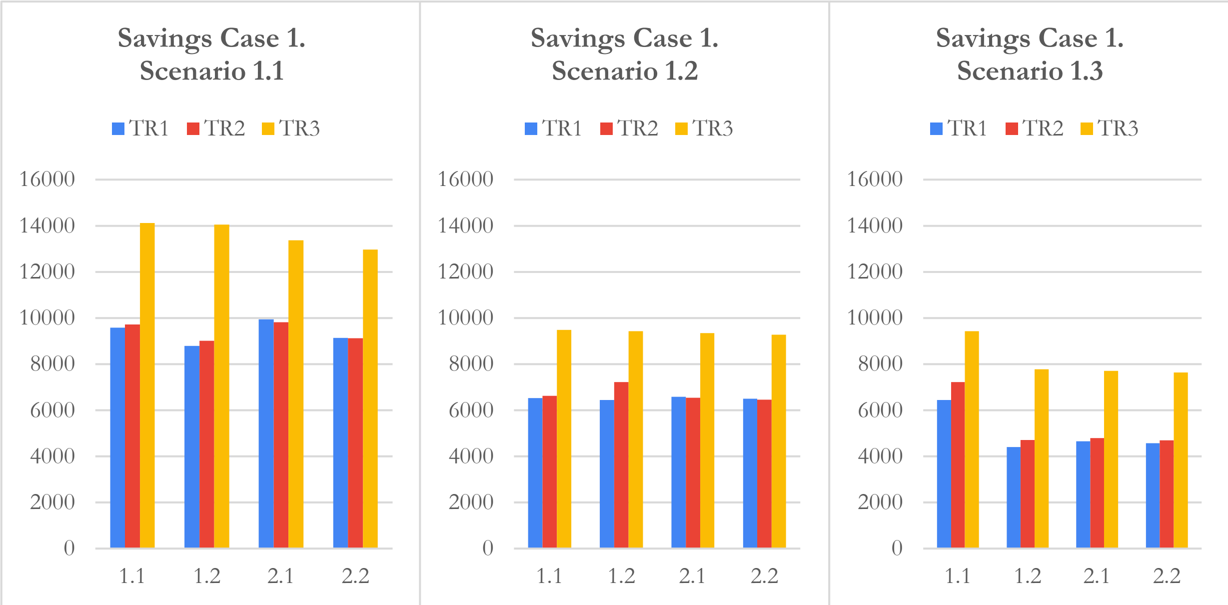

Figure 6: Savings Scenario 1, Case 1

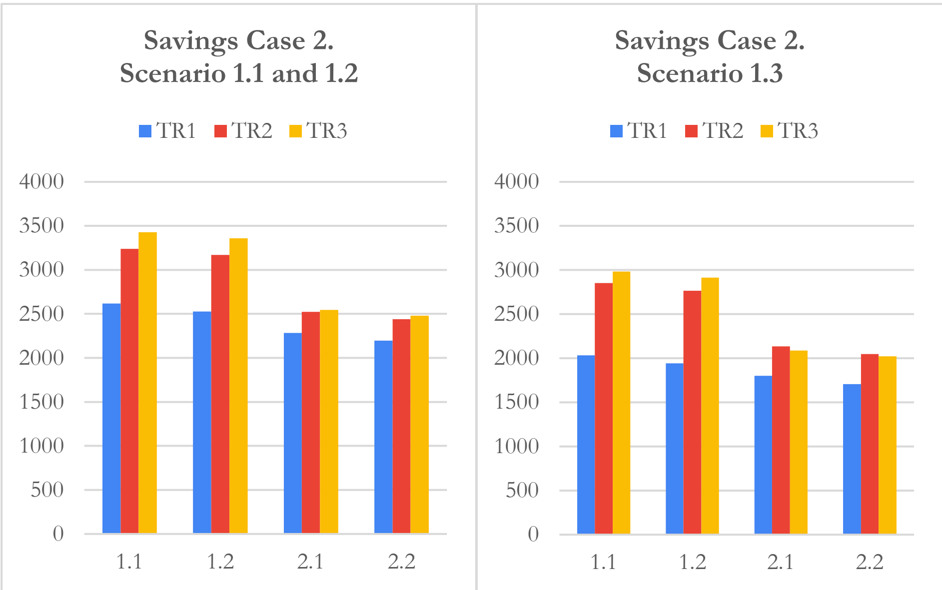

Figure 7: Savings Scenario 1, Case 2

Table 15: Explanatory table, Savings Scenario 1

Case 1	Battery, HEMS	Scenario 1.1	PV profile 1, Battery profile 1	Configuration 1.1	Retrofit, EV
Case 2	HEMS	Scenario 1.2	PV profile 1, Battery profile 2	Configuration 1.2	Retrofit, No EV
		Scenario 1.3	PV profile 2, Battery profile 2	Configuration 2.1	New House, EV
				Configuration 2.2	New House, no EV

6.2.4 Return of investment

The return of investment in a 15 years period has been calculated for every solution, considering the solutions explained and compared in Paragraph 5.2, and the costs showed in Appendix B. TESLA Powerwall 2.0 has been considered as battery solution for the evaluation, while SMA Sunny Home Manager 2.0 has been selected as HEMS. No interest rates and no subsidies from the government have been taken into account, nor a compensation from energy retailers or aggregators (i.e. Eneco CrowdNett).

Figure 8 shows the Return of Investment for Case 1 in Scenario 1.1, Scenario 1.2 and Scenario 1.3, and Figure 9 shows the return of Investment for Case 2 in Scenario 1.1 and Scenario 1.3. Other cases and sub-scenarios are shown in Appendix D and not here considered because not relevant for a comparison. ROI for every case of Scenario 1 are displayed in Table D 5 to Table D 12.

For Case 1, the ROI is remarkable with an investment in 2020 only considering a Tariff regime 3, and only in a scenario with a 13.5 kWh battery and an 8 kW PV system (scenario 1.1). For Scenario 1.2, it is close to zero, while in 1.3 it is negative. For an investment made in 2025 with TR3, the savings are appreciably positive in Scenario 1.1 and 1.2, while positive but close to zero in Scenario 1.3. Considering the other Tariff regimes, the ROI is positive with an investment in 2025 only in Scenario 1.1.

For Case 2, only the situation with an investment made in 2020 is being considered, since already convenient in most of the scenarios and tariff regimes. Considering a scenario with a 13.5 kWh battery and an 8 kW PV system (scenario 1.1), the ROI is higher in a tariff regime 2 or 3 compared to a tariff regime 1, and lower in configurations that consider a new building (Configuration 2). Indeed, being the electricity consumption for heating quite low, in general below 3000 kWh/year, the HEMS has less room for manoeuvre for boosting and reducing the consumption. Considering a scenario with a 6.5 kWh battery and a 4 kW PV system (scenario 1.3), the pattern is similar. In every considered configuration, the ROI is positive, meaning that the investment is convenient in a period of 15 years.

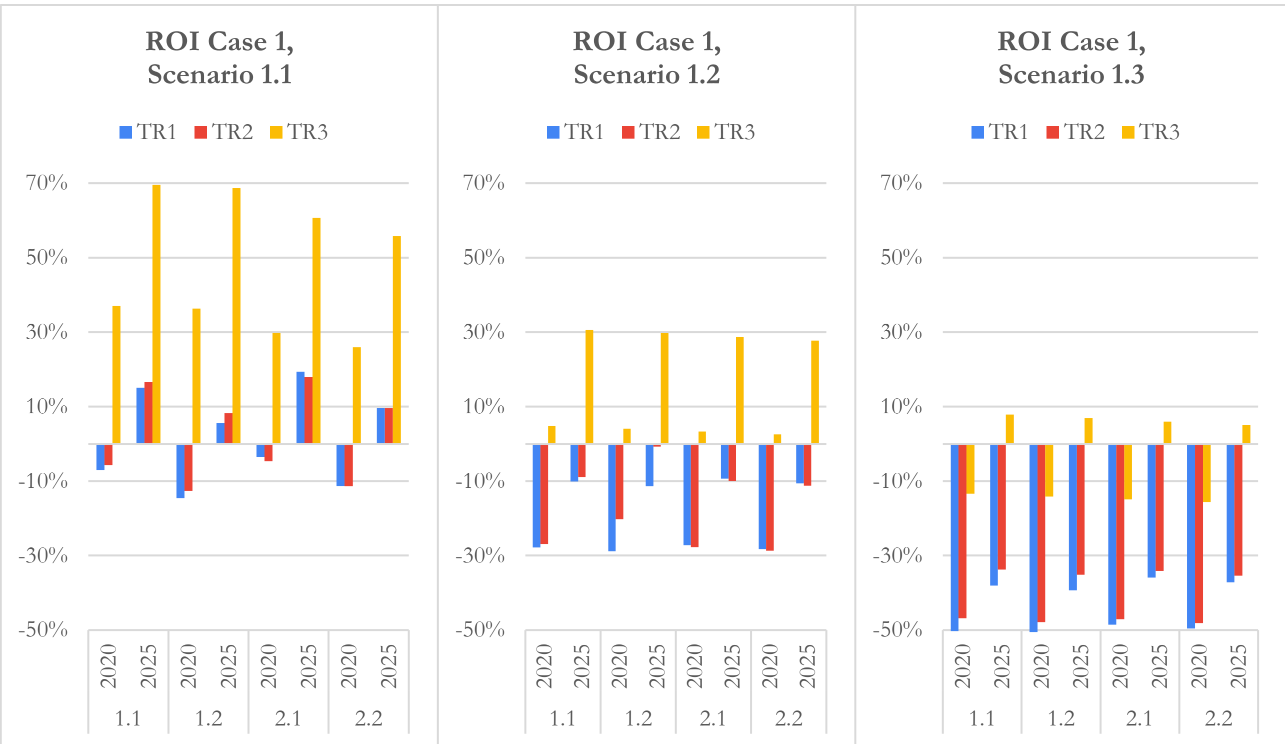

Figure 8: ROI Scenario 1, Case 1

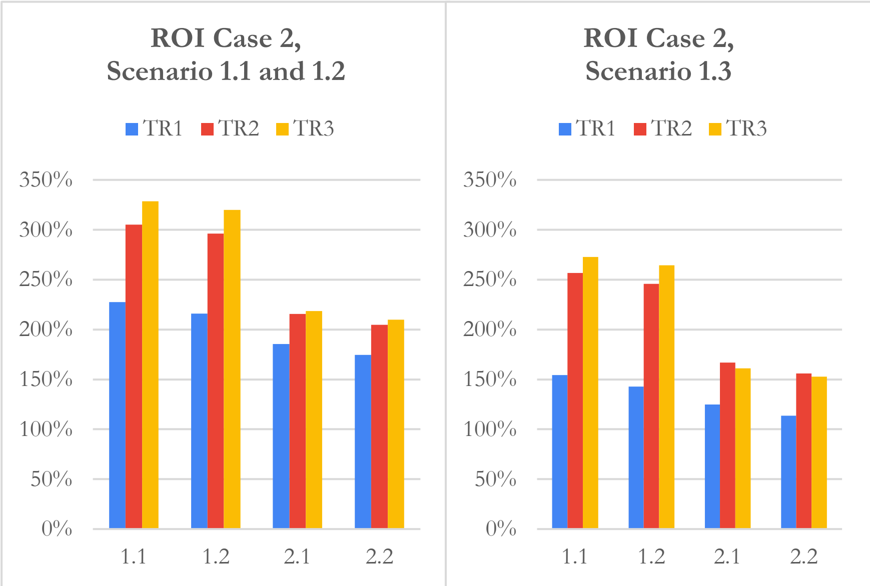

Figure 9: ROI Scenario 1, Case 2

6.2.5 Pay Back Time

The solution that includes a battery and a HEMS (Case 1) has a payback time of 13 years in the best scenario (Scenario 1.1 with TR3), considering an investment made in 2021, while 11 years and 8 months considering an investment made in 2023. Calculations are included in Appendix D (Table D 13 and Table D 14). The difference is caused by the increase in electricity cost and the decrease of the cost of the battery.

For the solutions that implement a HEMS without battery (case 2), the ROI is sufficiently high in every configuration, therefore the calculation of the payback time has been made considering an investment made already at the beginning at 2021. Calculations are included in Appendix D (Table D 15 to Table D 22).

For Scenario 1.1 and 1.2, the payback time (PBT) is less than 6 years for a retrofit (C1) and 7.3 years for a new building (C2), considering a tariff regime 3 (TR3).

For Scenario 1.3, the PBT is around 6 years for a retrofit (C1) and 8.6 years for a new building (C2), considering a tariff regime 3 (TR3).

Figure 10 displays a comparison of the accumulated monthly savings in 4 different situations for Case 2. The situations are created considering both configurations (C1 and C2) of Scenario 1.1 and Scenario 1.3. The value of 800€ in savings has been highlighted, since it gives a clear indication of when the Payback time is reached in the different situations.

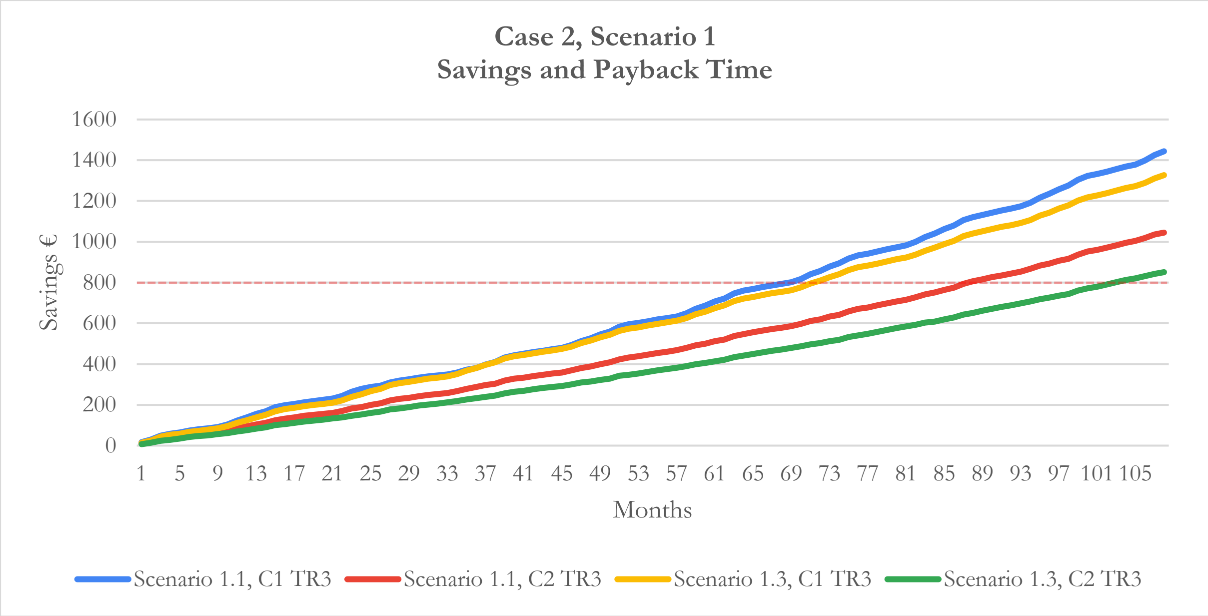

Figure 10: Accumulated Monthly Savings Comparison, Case 2

6.3 Scenario 2

In Scenario 2, the occupancy profile is represented by a retired couple. As mentioned in the introduction of Chapter 6, this profile is representative of the second most common client typology for Woon Duurzaam. Occupancy patterns have been designed following the guidance of Guerra Satin and Silvester (Guerra Satin & Silvester, 2017), with some adjustments.

6.3.1 Appliances Pattern

Compared to Scenario 1, the appliances pattern presents 2 main differences:

- **Time of use**: as the clients are spending at home most of the day (Guerra Satin & Silvester, 2017), peaks of consumption are not concentrated in the early morning and evening, but also in the middle of the day, due to cooking schedule.

- **Appliances efficiency:** while in scenario 1 appliances with the highest energy label have been taken into account, in this scenario the considered wet appliances (refrigerator, washing machine, dryer, dishwasher) have the second highest energy label found on the market. For example, if the refrigerator considered in Scenario 1 has a A+++ Energy label, the refrigerator considered in Scenario 2 has a A++ Energy label. The reason for this assumption is found in an observed tendency of older clients to renovating appliances less frequently. Also, Woon Duurzaam projects for older clients are usually retrofit plan, in which the house is mainly renovated in its thermal performance, and not in the appliances.

Table E 1 in Appendix E shows the appliances pattern for Scenario 2.

6.3.2 Heating Pattern

The heating pattern has been divided into 3 different settings: At home, Not at home, and Night. Each of these settings involves different temperatures for each room of the house, created having as a reference the work of (Guerra Satin & Silvester, 2017). It is possible to notice that the temperatures are generally higher compared to Scenario 1. This is due to different requirements in terms of thermal comfort for older people. Values are shown in Table 15.

Table 16: Rooms temperature for each heating setting, Scenario 2

Room	T °C (At home)	T °C (Not at home)	T °C (Night)
Living Room	22	18	18
Kitchen	22	18	18
Bedrooms	20	18	20
Guest Rooms	18	18	18
Bathrooms	22	18	18
Toilets	18	18	18
Working Rooms	22	18	18
Circulation areas	20	18	18
Storage Room	15	15	15

The day has been divided in 4 timeslots, and a heating setting has been assigned for each timeslot. Regarding the weekend, it has been assumed that the couple is out on Saturday for a great part of the day, while it stays at home on Sunday. The heat pump is on at night only in November, December, January, February, and March. From May to September, it only provides Domestic Hot Water. The heating pattern for Scenario 2 is shown in Table 16.

Table 17: Heating pattern for Scenario 2

	Time of the day			
Day	0-6	7-20	21-22	23-0
Weekdays and Sunday	Night	At home	At home	Night
Saturday	Night	Not at home	At home	Night

6.3.3 Savings Calculation

For the savings calculation, 3 sub-scenarios have been created:

1. **Scenario 2.1**
   In this sub-scenario, an 8 kW PV system has been considered (PV profile 1), together with a 13.5 kWh battery (Battery profile 1)

2. **Scenario 2.2**
   In this sub-scenario, an 8 kW PV system has been considered (PV profile 1), together with a 6 kWh battery (Battery profile 2)

3. **Scenario 2.3**
   In this sub-scenario, a 4 kW PV system has been considered (PV profile 2), together with a 6 kWh battery (Battery profile 2)

It has been noticed that the difference in heating requirement between a retrofit configuration and a new building configuration is small for Scenario 2, 5.2 kW at -5°C for the first configuration, 4.9 kW at -5°C for the second configuration. Therefore, only the configuration 1 (retrofit) has been considered.

Like in Scenario 1, the savings are calculated in the 2 different cases, as shown in the tables below. The savings are calculated comparing the total final electricity bill with the one of the Case 0, in which no battery or HEMS is considered. Savings for each case are calculated in the 3 tariffs regimes and displayed in Table 17, Table 18, and Table 19.

The electricity bill for each case, from which the savings have been calculated, are included in Appendix E (Table E 2, Table E 3, and Table E 4).

6.3.3.1 Scenario 2.1

Savings for Scenario 2.1 are shown in Table 17

Table 18: Savings Scenario 2.1

		Scenario 2.1 – PVP1, BP1		
		Savings over 15 years €		
		Configuration 1: Retrofit		
Sub-configuration 1: EV				
Case	Description	TR1	TR2	TR3
1	ev, battery, hems	7494	7598	11034
2	ev, hems	1003	974	1175
Sub-configuration 2: no EV				
Case	Description	TR1	TR2	TR3
1	battery, hems	6000	6352	11034
2	hems	900	973	1175

As a general pattern, it is possible to notice the follow:

- For **Case 1** (battery + HEMS)
  - No substantial difference is identified between a configuration with EV and a configuration without EV.
  - Savings are 45-70% higher with a type 3 Tariff regime (TR3), in every configuration and sub-scenario.
- For **Case 2** (HEMS)
  - No substantial difference is identified between a configuration with EV and a configuration without EV.
  - Savings are around 20% higher with a type 3 Tariff regime.

6.3.3.2 Scenario 2.2

Savings for Scenario 2.2 are displayed in Table 18

Table 19: Savings Scenario 2.2

		Scenario 2.2 – PVP1, BP2		
		Savings over 15 years €		
		Configuration 1: Retrofit		
Sub-configuration 1: EV				
Case	Description	TR1	TR2	TR3
1	ev, battery, hems	4967	5282	8522
2	ev, hems	1003	974	1175
Sub-configuration 2: no EV				
Case	Description	TR1	TR2	TR3
1	battery, hems	4694	5022	8522
2	hems	900	973	1175

As a general pattern, it is possible to notice the follow:

- For **Case 1** (battery + HEMS)
  - Savings are lower than in Scenario 2.1 but follow the same trends.
  - Savings are around 60% higher with TR3.
- For **Case 2** (HEMS)
  - Same as Scenario 2.1.

6.3.3.3 *Scenario 2.3*

Savings for Scenario 2.1 are shown in Table 19

Table 20: Savings Scenario 2.3

		Scenario 2.3 – PVP2, BP2		
		Savings over 15 years €		
		Configuration 1: Retrofit		
Sub-configuration 1: EV				
Case	Description	TR1	TR2	TR3
1	ev, battery, hems	3499	3627	7301
2	ev, hems	731	779	1014
Sub-configuration 2: no EV				
Case	Description	TR1	TR2	TR3
1	battery, hems	3298	3427	7301
2	hems	659	779	1014

As a general pattern, it is possible to notice the follow:

- For **Case 1** (battery + HEMS)
  - Savings are generally slightly higher when considering a Sub-configuration 1 (with EV) in TR1 and TR2, while they are the same in TR3.
  - Savings are higher with a type 3 Tariff regime (TR3), in every configuration and sub-scenario.
- For **Case 2** (HEMS)
  - Savings are generally lower compared to scenario 2.1 and 2.2
  - Savings are around 15% higher with TR3

Figure 11 and Figure 12 offer a graphical comparison for the two cases in the 2 configurations and sub-scenarios. Scenario 2.2 is not considered for case 2 because equal to scenario 2.1, since only the PV size is considered and not the battery size.

As a general overview, for Case 1, it is possible to notice the decreasing trend of the savings from Scenario 2.1 to Scenario 2.2, with savings in TR3 generally 30-80% higher compared to the other tariff regimes

For Case 2, savings are slightly lower in Scenario 2.3 compared to Scenario 2.1 and Scenario 2.2.

Figure 11: Savings Scenario 2, Case 1

Figure 12: Savings Scenario 2, Case 2

Table 21: Explanatory table, Savings Scenario 2

Case 1	Battery, HEMS	Scenario 2.1	PV profile 1, Battery profile 1	Configuration 1.1	Retrofit, EV
Case 2	HEMS	Scenario 2.2	PV profile 1, Battery profile 2	Configuration 1.2	Retrofit, No EV
		Scenario 2.3	PV profile 2, Battery profile 2		

6.3.4 Return of Investment

The return of investment in a 15 years period has been calculated for every solution, considering the cost of solutions mentioned in Paragraph 5.2. No subsidies from the government have been taken into account, nor a compensation from energy retailers or aggregators (i.e. Eneco CrowdNett).

Figure 13 shows the Return of investment for Case 1 in Scenario 2.1 and Scenario 2.2, and Figure 14 the return of Investment for Case 2 in Scenario 2.1 and Scenario 2.3. Other Cases and Sub-scenarios are shown in Appendix E and not here considered because not relevant for a comparison. ROI for every case of Scenario 1 are displayed in Table E 5 to Table E 10.

Compared to Scenario 1, it is possible to notice that the ROI is generally lower for every configuration and sub-scenario.

For Case 1, the ROI is barely positive with an investment in 2020 only considering a Tariff Regime 3, and only in a scenario with a 13.5 kWh battery and an 8 kW PV system (scenario 2.1). In the same scenario, but considering Tariff Regimes 1 and 2, the ROI becomes positive (but not consistent) only if the investment is made in 2025, when battery prices will become lower, and only considering a retrofit configuration with EV. Considering a scenario with the same PV system, but with a 6.5 kWh battery size (scenario 1.2), the ROI is positive just with an investment made in 2025 and only in a tariff regime 3 (TR3). The ROI is negative in all the other solutions.

For Case 2, the ROI is always positive in a scenario with an 8 kW PV system (2.1 and 2.2), being significantly higher with a TR3. Considering a scenario with a 4 kW PV system, the ROI is positive just in a TR3.

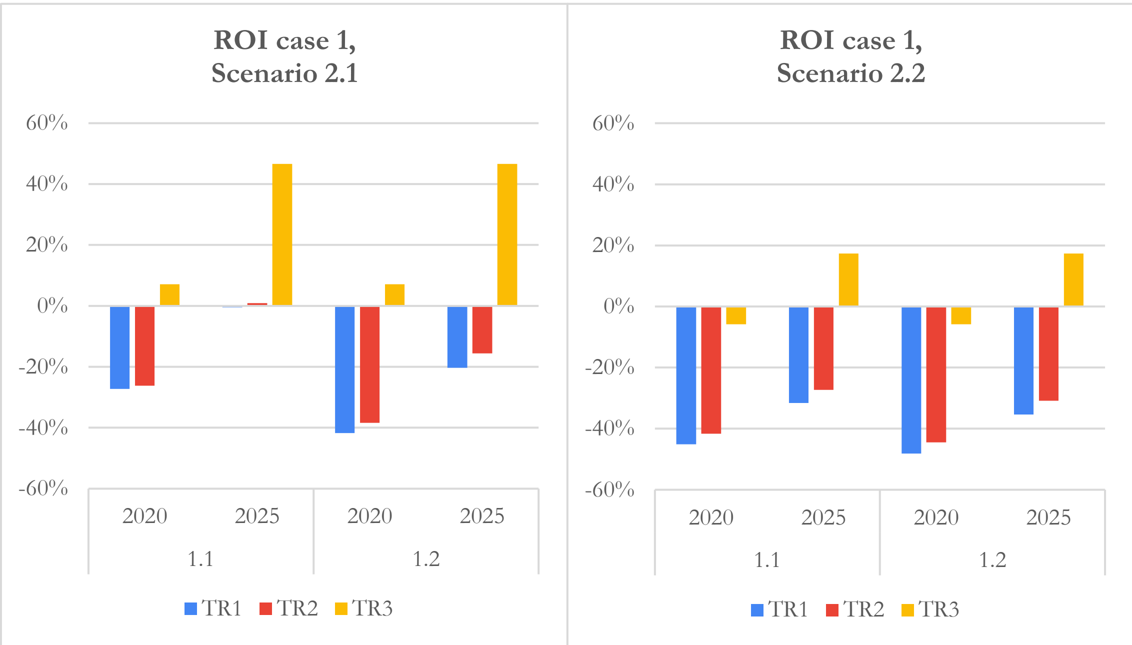

Figure 13: ROI Scenario 2, Case 1

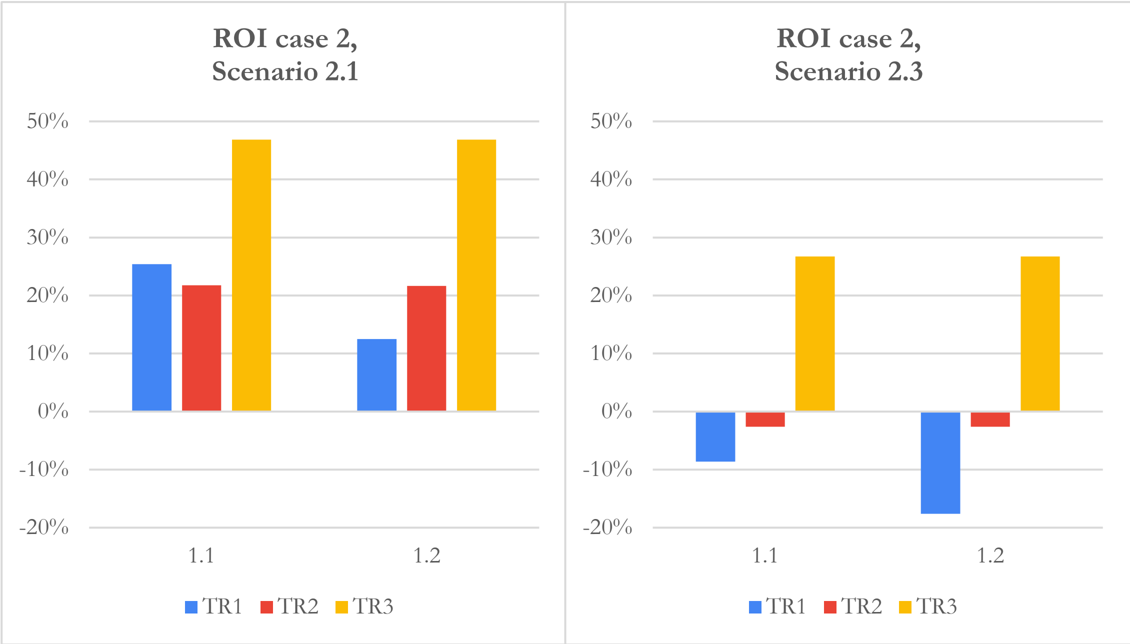

Figure 14: ROI Scenario 2, Case 2

6.4 Results and comments

The most important outcomes of the Tecno-Economic model are resumed and commented in the following paragraphs.

6.4.1 Case 1 (Solution with a battery system and HEMS)

For Scenario 1, the ROI is acceptably positive with an investment made in 2020 only within the frame of a Tariff Regime 3, and only if considering a battery size of around 13.5 kWh (both TESLA Powerwall 2 and LG CHEM RSU 13) coupled with an 8kW PV system (Scenario 1.1). Under these conditions, the payback time is 13 years, or 11 years and 8 months with an investment made in 2023. For the other tariff regimes, the investment become convenient only if made from 2025, and only when considering the TESLA Powerwall 2.

A ROI comparison between the TESLA Powerwall 2 and LG CHEM RESU 13 in scenario 1.1 is offered in Figure 15.

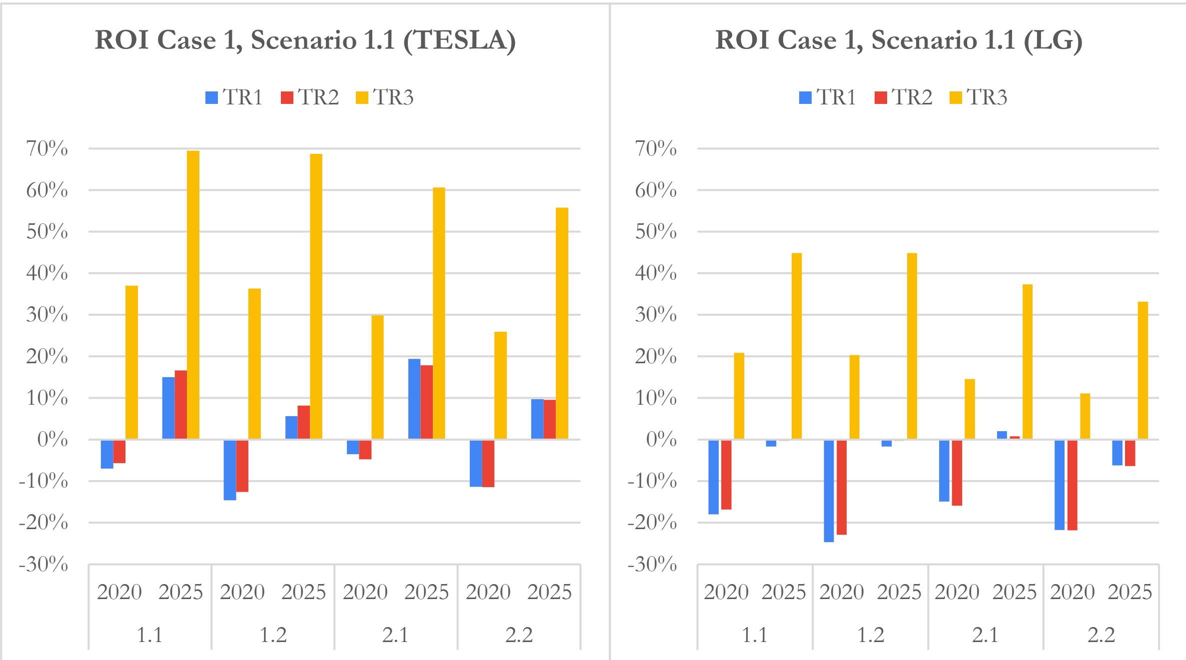

Figure 15: Comparison between TESLA Powerwall 2.0 and LG Chem RESU 13, Scenario 1.1

As already mentioned in Paragraph 5.2.2, the battery system proposed by TESLA is the cheapest in terms of €/kWh because it includes the battery cells and the battery inverter in a single solution. When buying batteries from other brands, like LG or BYD, the cost of the battery has to be added to the one of the hybrid inverter, making the solution more expensive.

When it comes to a scenario with the same size of PV system, but coupled with a smaller battery of 6.5 kWh, the ROI is only convenient in TR3 and with an investment made after 2025.

For Scenario 2, the ROI is positive but close to 0% considering an investment made in 2020 in TR3 and only in a configuration with a battery size of around 13.5 kWh (both TESLA Powerwall 2 and LG Chem RESU 13) coupled with an 8kW PV system (Scenario 2.1). With an investment made in 2025, the ROI becomes positive in TR3 also considering an 8kW PV system with a 6.5 kWh battery (Scenario 2.2). For all the other configurations, the ROI is negative.

6.4.2 Case 2 (Solution with a HEMS)

Investing in a HEMS without having battery is very convenient for a family (Scenario 1), due to a payback time between 5.8 and 8.6 years according to the different configurations. The investment is especially convenient when the electricity consumption for heating is above 3000 kWh/year: in this condition, the PBT is close to 6 years. This is generally the situation of a detached house built before the '80s and then recently renovated (configuration 1): Woon Duurzaam projects carried out with this house typology highlight a thermal requirement generally in the range of 6-9 kW at -5°C. When considering a newly built house, the thermal requirement is generally lower than 6 kW at -5°C, resulting in an electricity consumption for heating below 3000 kWh. In these conditions, a HEMS is still a good investment, but less convenient, with a PBT between 7.3 and 8.6 years. Worth mentioning is the relevant reduction of the ROI when considering a flat tariff (TR1), or a conservative off-peak tariff (TR2) when compared with a more advanced time-of-use tariff (TR3).

For Scenario 2, the ROI is positive in every tariff regime when considering a scenario with an 8 kWp PV system coupled with a 13.5 kWh battery, while negative or close to zero (for TR3) with a smaller battery and/or smaller PV system. Even in the most convenient scenario, however, the ROI is not enough to justify an investment, being the payback time close to 13 years. The reason for the reduced convenience of a HEMS in this scenario can be found in the different occupancy pattern of the clients, more constant throughout the whole day, coupled with a low electricity consumption from heating.

The considered final price of 800€ for purchasing and installing a HEMS has been considered after the discussion with the partner Zonnefabriek (Mensink, 2020). This price doesn't include all the marginal cost of the necessary components to ensure the smart energy management, such as appliances and devices able to communicate via EEBUS® with the Sunny Home Manager 2.0®. However, less than 10% of the savings come from the intelligent shifting of appliances cycle, and the rest is guaranteed by the control of the battery charging and discharging time, as well as of the heat pump power. Furthermore, the possibility to communicate via EEBUS® is guaranteed by most of the heat pumps sold by Woon Duurzaam, and that batteries sold in the future will be probably able to communicate to the HEMS by wired or wireless connection.

Finally, it has to be pointed out that the considered lifetime period of 15 years is quite conservative, especially for the HEMS. Thus, the convenience of the installation could be also higher than the one shown in this report.

7 Sales Volume Projection

7.1 Market Proposition

7.1.1 Monitoring

A product able to monitor energy consumption can bring savings for both the customer and Woon Duurzaam. The customer will be able to avoid wasting energy through immediately figuring out if anything is malfunctioning, also extending the lifetime of the installation. On the other side, Woon Duurzaam will save on its service and maintenance contract. Indeed, it is estimated that every 5 years the company will have to intervene to fix some malfunctioning of the installation: with the help of the monitoring system, Woon Duurzaam will be able to perform from distance 20% of the repairs (van Dijk, 2020).

7.1.2 Self-consumption maximisation

Since the ROI for a family scenario purchasing a HEMS is convincingly positive when considering time-of-use tariff, a calculation of the payback time has been performed taking into account an investment made at the beginning at 2021. Calculations are included in Appendix D. Under the best conditions (renovated building), the PBT is close to 6 years, while when considering a new building, the PBT is between 7.3 and 8.6 years.

According to the experience of the company, customers are willing to accept a PBT of maximum 7 years in order to make an investment, especially when considering products relatively new to the market such as HEMS (van Dijk, 2020). Thus, the investment becomes attractive for a family living in a renovated house, in which the electric consumption for heating is above 3000 kWh/year and the size of the PV system is above 4kWp. Regarding the other configurations investigated in this study, the investment could be still convincing when other added values are considered to be brought by the solution besides the financial one.

For example, a HEMS such as the SMA Sunny Home Manager 2.0® can monitor the consumption and production of energy, storing years of data. These data give an important insight regarding the general consumption and production pattern of the house, useful before making a decision on the best battery size to install (Mensink, 2020). Furthermore, the company could directly monitor the energy consumption and production of each client, offering a better maintenance at a lower price (Mensink, 2020). Another added value is the reduced dependency from the grid ensured by a HEMS, important in the current period of utilities price increase, combined with a more sustainable energy consumption of the house (van Dijk, 2020).

As shown in this study, the ROI and PBT for a battery installation will not be convincing before 2023-2025, due to the not competitive price of batteries, together with an absence of subsidies from the government (van Dijk, 2020). Still, there's a raising interest among clients, who start to ask information to the company in order to make the investment in the future. In this context, Woon Duurzaam would be able to sell a HEMS as an initial component of the future battery system also considering that, as seen in the techno-economic analysis, savings of a combination HEMS-battery are consistently higher than savings form the unique battery. Thus, a HEMS would be a good solution for clients already interested in batteries, and as well for those clients which match with the Scenario 1 considered in this study, which constitute around 65% of Woon Duurzaam clients.

7.2 Profit Calculation

7.2.1 Monitoring

Assuming that every repair takes 3 hours to be completed, and that the cost is 60€ per hour for the maintenance, the profit for the company for the monitoring proposal would be of 36€ per heat pump sold.

7.2.2 Self-consumption maximisation

In light of the findings of this research, it has been evaluated, together with Woon Duurzaam, that a HEMS solution could be included in the house renovation quotation for 20-30% of the clients. The current average package of 15000€ for each client would be thus increased to 15200€. Consequently, revenues from home renovations will increase of 1.3% and the gross margin of 1%. This results in a net profit increase of €1.478.300 in 2023. Figure 16 and Figure 17 show the trend in Gross Margin and Net Profit before and after the implementation of the Self-Consumption maximisation proposal. Full calculations are included in Table F 1 and Table F 2.

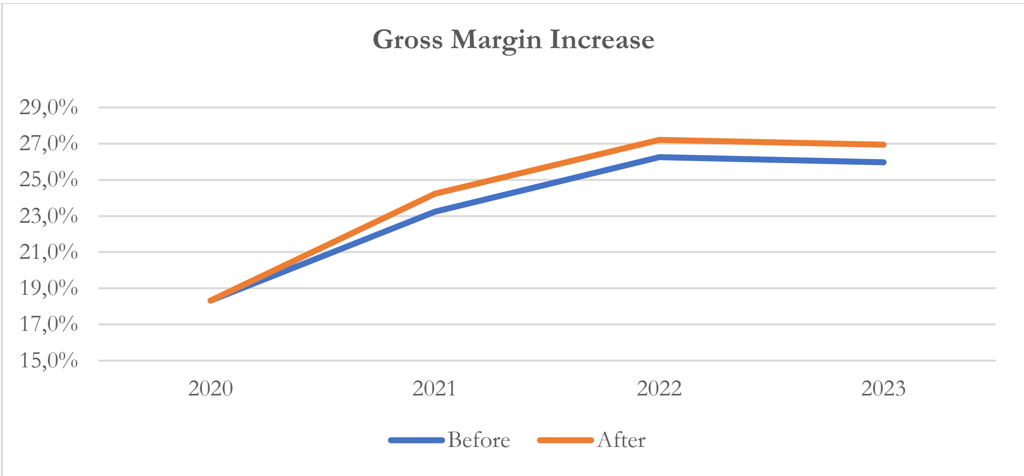

Figure 16: Gross Margin Increase, Self Consumption Maximisation Proposal

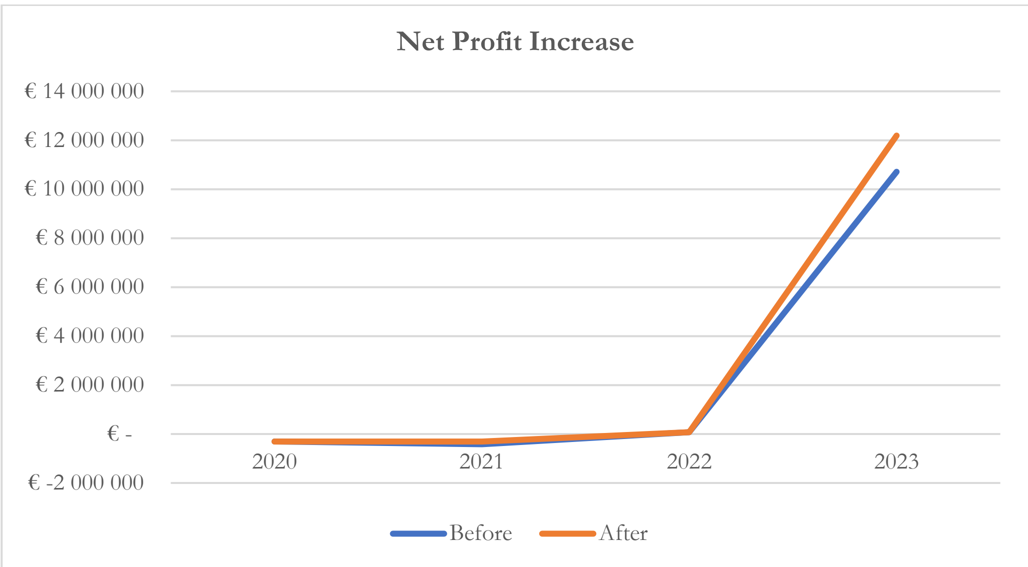

Figure 17: Net Profit Increase, Self Consumption Maximisation Proposal

8 Conclusion

In this project, the business case has been studied for solutions able to monitor the energy behaviour and maximise the electricity self-consumption of Dutch households, in preparation for the gradual phasing out of the net metering policy starting from 2023. Investigated products were batteries, home energy management systems and hybrid inverters, together with simpler solutions like energy monitors. After the initial research, only batteries and home energy management systems have been considered for further analysis and return of investment calculation.

The savings guaranteed by each solution have been calculated with a Techno-Economic model based on a MATLAB algorithm. Two client scenarios have been created in order to reflect the most typical Woon Duurzaam client profiles, the one of a family and the one of a retired couple. For each scenario, different configurations have been created and simulated by varying the thermal performance of the house, the size of the PV system and battery, and considering or not the adoption of an electric vehicle. Electricity consumed, produced, and stored in each configuration have been simulated for every hour of the day, and for 15 years, together with the hourly electricity bill. In particular, 3 cases have been simulated for each configuration: without considering any smart storage or HEMS solution, with the use of a battery, with the use of a battery coupled with a HEMS, and with the implementation of a HEMS without battery. Savings for every case and every configuration have been calculated considering different electricity tariff regimes.

As a general conclusion, the simulations have highlighted that an investment in a battery and/or HEMS is more favourable when done in a time-of-use or dynamic tariff regime, for clients who charges an electric vehicle at home and who lives in houses that consumes more than 3000 kWh/year of electricity for space heating. Also, the investment is generally only fruitful if made by a client profile matching with the one of a family.

The investment in a HEMS solution is the most convenient among the analysed ones, even if already made in 2020-2021, thanks to a payback time that ranges from 5.8 to 8.6 years for a family client profile according to the different configurations. The investment in a battery system coupled with HEMS, if made in 2020-2021, results in a payback time of 13 years under the most favourable conditions. Thus, this investment is not enough remunerative to be justified now, also considering that injecting electricity into the grid will be still convenient until the end of 2022, and that the government has not prepared yet a subsidy scheme for battery purchases.

In light of the results of this study, a market proposition has been developed for Woon Duurzaam in order to start selling HEMS solutions already from 2020-2021. This system not only allows clients to save on the electricity bill through a smart management of the energy consumption, but it would also enable a precise monitoring, with the creation of a database of the consumption and production pattern of the house. The provided information would be useful before deciding on the best battery size to install in the house. Thus, the HEMS could be sold to clients asking for a battery, in guise of the initial component of the future battery system.

Furthermore, the database created by the HEMS, as well as by more simple energy monitoring solutions analysed in this study, can be used by the company to improve its maintenance contract.

The market proposition could be further improved with a study on the potential savings guaranteed by offering a hybrid inverter when installing a new PV system. Indeed, for customers who are installing a PV system and are willing to invest on a battery in the future, the purchase of a single hybrid inverter is more convenient when compared to buying a solar inverter and coupling it with a battery inverter later.

A discussion with Eneco Crowdnett should be also brought forward for a possible future collaboration, and further investigations should be also performed on similar projects, which can ensure homeowners to get rewarded in exchange of crowd balancing services offered to the grid.

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Appendix A

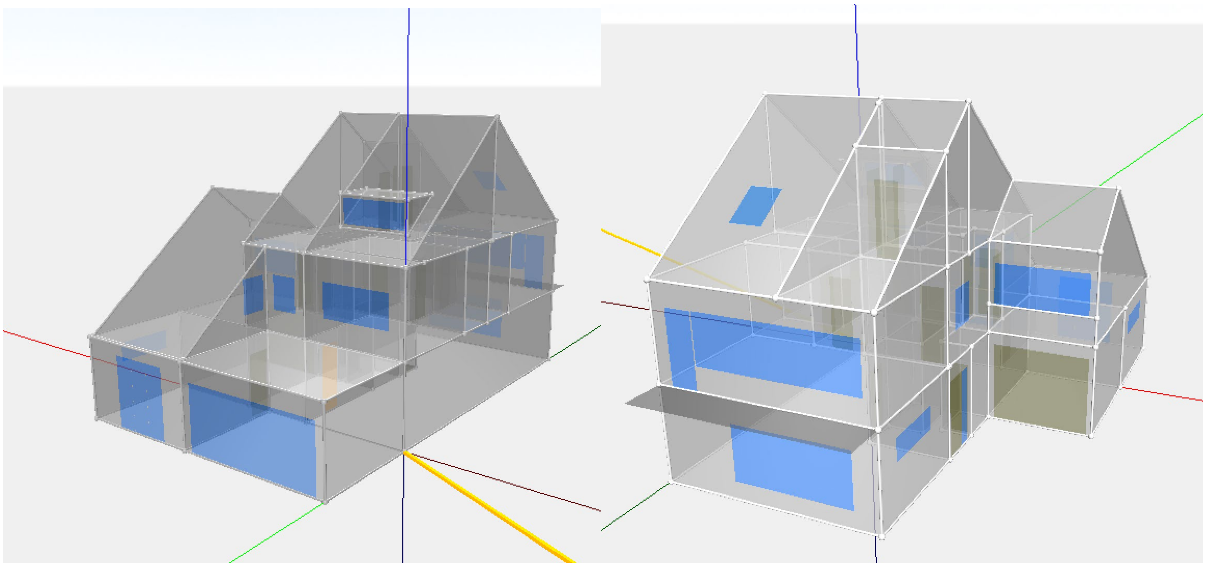


Figure A 1: 3D model of the house

Vermogen lucht-water warmtepomp aroTHERM plus 5kW - Verwarmen

5kW : COP W35-30

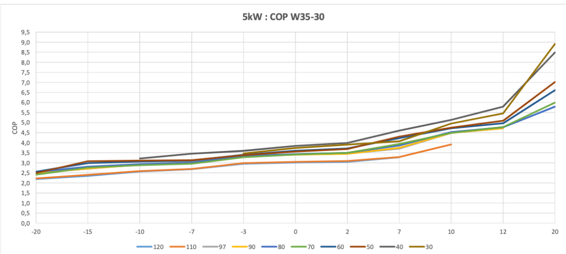
Compressor speed (rps)

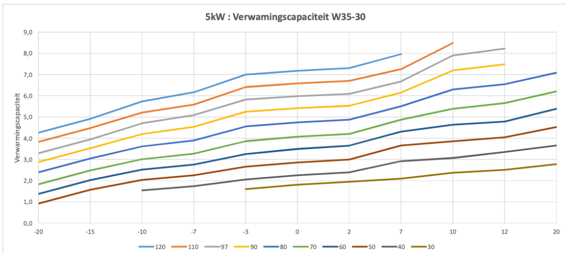
						40%	50%	60%		
Outdoor air temperature	120	110	97	90	80	70	60	50	40	30
-20	2,2	2,2	2,5	2,5	2,5	2,4	2,6	2,5		
-15	2,4	2,4	2,7	2,7	2,8	2,8	3,0	3,1		
-10	2,6	2,6	2,9	2,9	2,9	2,9	3,1	3,1	3,2	
-7	2,7	2,7	3,1	3,0	3,0	2,9	3,1	3,1	3,4	
-3	3,0	3,0	3,3	3,3	3,3	3,3	3,4	3,4	3,6	3,5
0	3,0	3,0	3,4	3,4	3,4	3,4	3,6	3,6	3,8	3,7
2	3,1	3,1	3,4	3,4	3,5	3,5	3,7	3,7	4,0	3,9
7	3,3	3,3	3,7	3,7	3,9	3,9	4,2	4,3	4,6	4,1
10		3,9	4,5	4,5	4,5	4,5	4,7	4,7	5,1	5,0
12			4,7	4,7	4,8	4,8	5,0	5,1	5,8	5,5
20					5,8	6,0	6,6	7,0	8,5	8,9

5kW : Verwamingscapaciteit W35-30

Compressor speed (rps)

						40%	50%	60%		
Outdoor air temperature	120	110	97	90	80	70	60	50	40	30
-20	4,3	3,8	3,3	2,9	2,4	1,8	1,4	0,9		
-15	4,9	4,5	3,9	3,5	3,0	2,5	2,0	1,6		
-10	5,7	5,2	4,7	4,2	3,6	3,0	2,5	2,0	1,5	
-7	6,2	5,6	5,1	4,5	3,9	3,3	2,8	2,2	1,7	
-3	7,0	6,4	5,8	5,2	4,6	3,9	3,3	2,7	2,1	1,6
0	7,2	6,6	6,0	5,4	4,7	4,1	3,5	2,9	2,3	1,8
2	7,3	6,7	6,1	5,5	4,9	4,2	3,7	3,0	2,4	2,0
7	8,0	7,3	6,7	6,2	5,5	4,9	4,3	3,7	2,9	2,1
10		8,5	7,9	7,2	6,3	5,4	4,6	3,9	3,1	2,4
12			8,2	7,5	6,5	5,7	4,8	4,0	3,4	2,5
20					7,1	6,2	5,4	4,5	3,7	2,8





Vermogen lucht-water warmtepomp aroTHERM plus 7kW - Verwarmen

7kW : COP W35-30

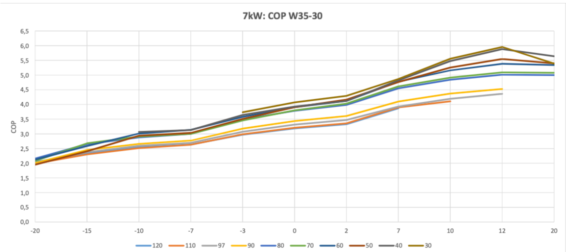
Compressor speed (rps)

						40%	50%	60%		
Outdoor air temperature	120	110	97	90	80	70	60	50	40	30
-20	2,0	2,0	2,0	2,0	2,2	2,1	2,1	1,9		
-15	2,3	2,3	2,4	2,5	2,7	2,7	2,6	2,4		
-10	2,5	2,5	2,6	2,7	2,9	2,9	3,0	2,9	3,1	
-7	2,6	2,6	2,7	2,8	3,0	3,0	3,1	3,0	3,1	
-3	3,0	3,0	3,1	3,2	3,5	3,5	3,6	3,5	3,6	3,7
0	3,2	3,2	3,3	3,4	3,8	3,8	3,9	3,9	3,9	4,1
2	3,3	3,4	3,5	3,6	4,0	4,0	4,1	4,2	4,1	4,3
7	3,9	3,9	3,9	4,1	4,5	4,6	4,8	4,8	4,8	4,9
10		4,1	4,2	4,4	4,8	4,9	5,2	5,3	5,5	5,6
12			4,4	4,5	5,0	5,1	5,4	5,6	5,9	6,0
20					5,0	5,1	5,3	5,4	5,6	5,4

7kW : Verwamingscapaciteit W35-30

Compressor speed (rps)

						40%	50%	60%		
Outdoor air temperature	120	110	97	90	80	70	60	50	40	30
-20	5,8	5,1	4,4	3,9	3,4	2,9	2,4	1,8		
-15	6,6	5,9	5,2	4,7	4,0	3,6	2,9	2,1		
-10	7,6	6,8	6,1	5,5	4,8	4,3	3,8	3,0	2,4	
-7	8,0	7,2	6,4	5,8	5,1	4,5	4,0	3,2	2,5	
-3	9,2	8,3	7,5	6,8	6,0	5,3	4,6	3,7	3,0	2,4
0	9,9	9,0	8,1	7,4	6,6	5,9	5,1	4,2	3,2	2,6
2	10,4	9,5	8,6	7,9	7,0	6,3	5,4	4,5	3,4	2,8
7	12,3	11,1	9,8	9,0	8,1	7,2	6,3	5,1	4,0	3,2
10		11,7	10,3	9,4	8,4	7,5	6,6	5,4	4,3	3,4
12			10,6	9,7	8,6	7,6	6,8	5,6	4,5	3,5
20					8,9	8,0	7,0	5,9	4,8	3,7



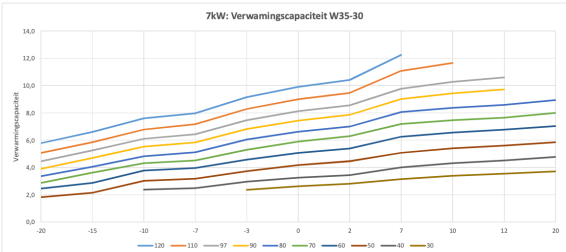


Figure A 2: Vaillant Heat Pump Specifictions

Appendix B

Table B 1: Monitoring Products Specifications and Prices

			1 phase		3 phase	
Product	**Functionalities**	**Component**	**Partial €**	**Total €**	**Partial €**	**Total €**
IUNGO	Configuration 1 Heat pump and solar panels	Iungo energy controller Breakoutbox 1phase gross production meter	189 25 38,5	252	189 25 81,5	295
	Configuration 2 Heat pump and solar panels + EV charger	Iungo energy controller 1phase or 3phase modbus kWh meter Modbus USB Stick Package	189 55 35	279	189 160 35	384
CEMM	Heat pump and solar panels	Cemm basic 2 pulse kwh meter + s0 cables S0 splitter	179 25 2,5	206	179 75 2,5	256
	Heat pump and solar panels + EV charger	Cemm plus 2 pulse kwh meter + s0 cables 1 kwh meter with modbus S0 splitter	239 25 55 2,5	320	239 75 95 2,5	410
ENELOGIC YOULESS	PV panels, EV, heat pump	1phase or 3 phase Meter	99	99	135	135
HomeWizard	PV panels, EV, heat pump	Wi-Fi P1 Meter	29	79		
		1phase or 3 phase Meter	50			

Table B 2: HEMS Prices

Brand	**Product**	**Price**
Smappee	Infinity	850€
Geo	Core	unknown
SMA	Sunny Home Manager 2.0®	800€
Solarwatt	EnergyManager	unknown

Appendix C

Table C 1: PV system specifications

PV production:	
Latitude (deg N):	52.3
Longitude (deg E):	4.77
Elevation (m):	-2
DC System Size (kW):	8 (PV Profile 1) 4 (PV Profile 2)
Module Type:	Standard
Array Type:	Fixed (roof mount)
Array Tilt (deg):	33
Array Azimuth (deg):	180
System Losses:	14.08
Invert Efficiency:	96
DC to AC Size Ratio:	1.2

Table C 2: EV charging system

EV Charger	Load capacity	Full Charging time
EVBox 1 phase, 16A	3.7 kW	11h00m

Table C 3: EV properties and assumptions

Car: Nissan LEAF®	
Autonomy	240 km
Battery Capacity	40 kWh
Autonomy per kWh	6 km/kWh
Average car distance	60 km/day (scenario 1)
Daily consumption	10 kwh/day (scenario 1)
Time of recharge	from midnight
Average time of recharge	2,7 hours (scenario 1)

Table C 4: Occupancy profiles (number of people indicated by numbers) and artificial lighting profiles (background colour) per household type

		23:00–06:00 Bedrooms	06:00–09:00 Living room	09:00–12:00 Living room	12:00–15:00 Living room	15:00–18:00 Living room	18:00–23:00 Living room
1 senior	Mon–Wed	1	1	1	1	1	1
	Thu	1	1	1		1	1
	Fri	1	1				1
	Sat–Sun	1					
1 adult	Mon–Tues	1	1	1	1	1	1
	Wed	1	1			1	1
	Thu	1	1				1
	Fri–Sat	1					
	Sun						
2 adults	Mon–Wed	2	2	2	2	2	2
	Thu–Fri	2	2				2
	Sat–Sun	2					
2 seniors	Mon–Thu	2	2	2	2	2	2
	Fri	2	2				2
	Sat	2	2				
	Sun	2					
3 adults	Mon–Wed	1/1/1*	1/1/1*	1/1/1*	1/1/1*	1/1/1*	1/1/1*
	Thu	1/1/1*	1/1/1*			1/1/1*	1/1/1*
	Fri	1/1/1*	1/1/1*				1/1/1*
	Sat–Sun	1/1/1*					
Single parent	Mon–Tues	1/1/1*	3*	3*	3*	3*	3*
	Wed	1/1/1*	3*	3*		3*	3*
	Thu	1/1/1*	3*			3*	3*
	Fri	1/1/1*	3*				3*
	Sat–Sun	1/1/1*					
Nuclear	Mon–Wed	2/1*	3*	3*	3*	3*	3*
	Thu	2/1*	3*			3*	3*
	Fri	2/1*	3*				3*
	Sat	2/1*					3*
	Sun	2/1*					

Notes: (1/1/1*) one person in each bedroom; (2/1*) two persons in the main bedroom, one in second bedroom; (3*) three or more persons, according to household type.
Black background = lights and appliances on from 23:00 to 24:00 and from 05:00 to 06:00 hours; grey background = lights and appliances on (during the winter period).

Table C 5: Heating Profiles (°C) per household type

		23:00–06:00		06:00–09:00		09:00–12:00		12:00–15:00		15:00–18:00		18:00–23:00	
1 senior		T1	T2/T3	T1	T2/T3	T1	T2/T3	T1	T2/T3	T1	T2/T3	T1	T2/T3
	Mon–Wed	20	20	22	22	23	22	23	22	23	22	24	22
	Thu	20	20	22	22	23	22	21	21	23	22	24	22
	Fri	20	20	22	22	21	21	21	21	21	21	24	22
	Sat–Sun	20	20	21	21	21	21	21	21	21	21	21	21
1 adult		T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
	Mon–Tues	10	10	12	12	14	14	14	14	14	14	17	14
	Wed	10	10	12	12	10	10	10	10	14	14	17	14
	Thu	10	10	12	12	10	10	10	10	10	10	17	14
	Fri–Sun	10	10	10	10	10	10	10	10	10	10	10	10
	*T3–10°C												
2 adults		T1	T2/T3	T1	T2/T3	T1	T2/T3	T1	T2/T3	T1	T2/T3	T1	T2/T3
	Mon–Wed	15	15	17	17	18	18	18	18	19	18	20	18
	Thu–Fri	15	15	17	17	16	16	16	16	16	16	20	18
	Sat–Sun	15	15	16	16	16	16	16	16	16	16	16	16
2 seniors		T1/T3	T2	T1/T3	T2	T1/T3	T2	T1/T3	T2	T1/T3	T2	T1/T3	T2
	Mon–Thu	19	19	21	21	22	21	22	21	22	21	23	21
	Fri	19	19	21	21	20	20	20	20	20	20	23	21
	Sat	19	19	21	21	20	20	20	20	20	20	20	20
	Sun	19	19	20	20	20	20	20	20	20	20	20	20
3 adults		T1/T3	T2	T1/T3	T2	T1/T3	T2	T1/T3	T2	T1/T3	T2	T1/T3	T2
	Mon–Wed	17	16	17	16	18	16	18	16	19	16	20	16
	Thu	17	16	17	16	16	16	16	16	19	16	20	16
	Fri	17	16	17	16	16	16	16	16	16	16	20	16
	Sat–Sun	17	16	16	16	16	16	16	16	16	16	16	16
Single parent		T1/T2	T3	T1/T2	T3	T1/T2	T3	T1/T2	T3	T1/T2	T3	T1/T2	T3
	Mon–Tues	15	15	17	15	19	15	19	15	19	15	20	15
	Wed	15	15	17	15	19	15	16	15	19	15	20	15
	Thu	15	15	17	15	16	15	16	15	19	15	20	15
	Fri	15	15	17	15	16	15	16	15	16	15	20	15
	Sat–Sun	15	15	16	15	16	15	16	15	16	15	16	15
Nuclear		T1/T2	T3	T1/T2	T3	T1/T2	T3	T1/T2	T3	T1/T2	T3	T1/T2	T3
	Mon–Wed	18	18	18	18	19	18	19	18	19	18	20	18
	Thu	18	18	18	18	16	16	16	16	19	18	20	18
	Fri	18	18	18	18	16	16	16	16	16	16	20	18
	Sat	18	18	16	16	16	16	16	16	16	16	20	18
	Sun	18	18	16	16	16	16	16	16	16	16	16	16

Notes: T1 = thermostat 1 (main thermostat, usually in the living room); T2 = thermostat 2 (radiators temperature in bedrooms); T3 = thermostat 3 (radiators temperature in office, bathroom and kitchen).
Black background = night setback temperature;
grey background = day setback temperature.

Appendix D

Table D 1: Appliances Pattern for Scenario 1

Appliance	N	Power Rating (W)	Standby Power (W)	Consumption per Cycle (kWh)	Use (duration, time)	Source
Continuously used						
Internet Router	1	10				(energuide.be, 2020)
Telephone	1	4	2			(energuide.be, 2020)
Refrigerator (A+++)	1	20				(Coolblue, 2020)
Food Preparation						
Coffee Machine	1	1000			5 minutes, 7-8	(energuide.be, 2020)
Toaster	1	1200			3 minutes, 7-8	(energuide.be, 2020)
Kettle	1	1300			3 minutes, 7-8	(energuide.be, 2020)
Microwave oven	1	1150			12 minutes, 7-9 12 minutes, 12-1 (Mo, We, Su) 12 minutes, 19-21	(energuide.be, 2020)
Cooker Hood (A)	1	75			2 hours, 12-14 (Mo, We, Su) 36 minutes, 19-21	(energuide.be, 2020)
Induction hob	1	1600			36 minutes, 7-9 2 hours, 12-14 (Mo, We, Su) 36 minutes, 19-21	(energuide.be, 2020)
Electric Oven	1	1900			36 minutes, 19-21	(energuide.be, 2020)
Cleaning						
Iron	1	900			30 minutes, 7-8	(energuide.be, 2020)
Washing machine (A+++-20%)	1			0.73	200 cycles/year, 2 hours per cycle (Mo,We,Fr,Su) 0-2	(Coolblue, 2020)
Dryer (A+++)	1			0.69	200 cycles/year, 2 hours per cycle (Mo,We,Fr,Su) 9-11	(Coolblue, 2020)
Vacuum Cleaner	1	800			4 hours, 10-14	(energuide.be, 2020)
Dishwasher (A+++)	1			0.84	5 cycles/week, 2 hours/cycle (Mo,Tu,Th,Fr,Su), 2-4	(Coolblue, 2020)
ICE						
LED TV	1	62	0.0002		1 hour, 17-18. 4 hours, 20-0	(energuide.be, 2020)
Computer	2	140			6 hours, 17-23	(energuide.be, 2020)
Laptop	2	60			4 hours, 0-4	(energuide.be, 2020)
Home Audio	1	95	1		1 hour, 17-18. 4 hours, 20-0	(energuide.be, 2020)
Printer	1	350			9.6 minutes, 16-17	(energuide.be, 2020)
Game Console	1	80	3		2 hours, 16-18	(DaftLogic, 2020)
Lighting						
Low Energy light bulbs	45	12			6-9 (100%), 9-16 (10%, Mo,We), 16-18 (50%), 18-0 (100%)	(GCEA, 2020)

Table D 2: Electricity Bill Scenario 1.1

		Scenario 1.1 – PVP1, BP1					
		Electricity Bill over 15 years €					
		Configuration 1: Retrofit			**Configuration 2: New building**		
Sub-configuration 1: EV							
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
0	ev	55357	52092	51892	45353	42534	42337
1	ev, battery, hems	45778	42379	37780	35415	32719	28964
2	ev, hems	52738	48852	48464	43070	40009	39790
		Sub-configuration 2: no EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
0		37013	35188	37243	27008	25630	27687
1	battery, hems	28218	26182	23198	17874	16506	14717
2	hems	34486	32018	33883	24812	23191	25208

Table D 3: Electricity Bill Scenario 1.2

		Scenario 1.2 – PVP1, BP2					
		Electricity Bill over 15 years €					
		Configuration 1: Retrofit			**Configuration 2: New building**		
Sub-configuration 1: EV							
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
0	ev	55357	52092	51892	45353	42534	42337
1	ev, battery, hems	48825	45475	42403	38766	35992	32989
2	ev, hems	52738	48852	48464	43070	40009	39790
		Sub-configuration 2: no EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
0		37013	35188	37243	27008	25630	27687
1	battery, hems	30573	28663	27821	20514	19178	18407
2	hems	34486	32018	33883	24812	23191	25208

Table D 4: Electricity Bill Scenario 1.3

		Scenario 1.3 – PVP2, BP2					
		Electricity Bill over 15 years €					
		Configuration 1: Retrofit			Configuration 2: New building		
Sub-configuration 1: EV							
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
0	ev	63335	59859	59947	52990	49974	50033
1	ev, battery, hems	58835	55049	52110	48334	45186	42332
2	ev, hems	61301	57006	56964	51190	47840	47945
		Sub-configuration 2: no EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
0		44991	42955	45297	34646	33070	35384
1	battery, hems	40583	38240	37528	30082	28373	27750
2	hems	43049	40188	42382	32938	31022	33363

Table D 5: ROI Scenario 1.1, TESLA Powerwall 2.0, 2020

		Scenario 1.1 – PVP1, BP1					
		ROI over 15 year (TESLA Powerwall 2.0, 2020)					
		Configuration 1: Retrofit			Configuration 2: New building		
		Sub-configuration 1: EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	ev, battery, hems	-7%	-6%	37%	-4%	-5%	30%
2	ev, hems	227%	305%	329%	185%	216%	218%
		Sub-configuration 2: no EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	battery, hems	-15%	-13%	36%	-11%	-11%	26%
2	hems	216%	296%	320%	175%	205%	210%

Table D 6: ROI Scenario 1.1, TESLA Powerwall 2.0, 2025

		Scenario 1.1 – PVP1, BP1					
		ROI over 15 year (TESLA Powerwall 2.0, 2025)					
		Configuration 1: Retrofit			Configuration 2: New building		
		Sub-configuration 1: EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	ev, battery, hems	15%	17%	70%	19%	18%	61%
2	ev, hems	227%	305%	329%	185%	216%	218%
		Sub-configuration 2: no EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	battery, hems	6%	8%	69%	10%	10%	56%
2	hems	216%	296%	320%	175%	205%	210%

Table D 7: ROI Scenario 1.1, LG Chem RESU 13, 2020

		Scenario 1.1 – PVP1, BP1					
		ROI over 15 year (LG Chem RESU 13, 2020)					
		Configuration 1: Retrofit			Configuration 2: New building		
		Sub-configuration 1: EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	ev, battery, hems	-18%	-17%	21%	-15%	-16%	15%
2	ev, hems	227%	305%	329%	185%	216%	218%
		Sub-configuration 2: no EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	battery, hems	-25%	-23%	20%	-22%	-22%	11%
2	hems	216%	296%	320%	175%	205%	210%

Table D 8: ROI Scenario 1.1, LG Chem RESU 13, 2025

		Scenario 1.1 – PVP1, BP1					
		ROI over 15 year (LG Chem RESU 13, 2025)					
		Configuration 1: Retrofit			Configuration 2: New building		
		Sub-configuration 1: EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	ev, battery, hems	-2%	0%	45%	2%	1%	37%
2	ev, hems	227%	305%	329%	185%	216%	218%
		Sub-configuration 2: no EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	battery, hems	-10%	-8%	44%	-6%	-6%	33%
2	hems	216%	296%	320%	175%	205%	210%

Table D 9: ROI Scenario 1.2, LG Chem RESU 6.5, 2020

		Scenario 1.2 – PVP1, BP2					
		ROI over 15 year (LG Chem RESU 6.5, 2020)					
		Configuration 1: Retrofit			**Configuration 2: New building**		
		Sub-configuration 1: EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	ev, battery, hems	-28%	-27%	5%	-27%	-28%	3%
2	ev, hems	227%	305%	329%	185%	216%	218%
		Sub-configuration 2: no EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	battery, hems	-29%	-20%	4%	-28%	-29%	3%
2	hems	216%	382%	320%	175%	205%	210%

Table D 10: ROI Scenario 1.2, LG Chem RESU 6.5, 2025

		Scenario 1.2 – PVP1, BP2					
		ROI over 15 year (LG Chem RESU 6.5, 2025)					
		Configuration 1: Retrofit			**Configuration 2: New building**		
		Sub-configuration 1: EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	ev, battery, hems	-10%	-9%	31%	-9%	-10%	29%
2	ev, hems	227%	305%	329%	185%	216%	218%
		Sub-configuration 2: no EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	battery, hems	-11%	-1%	30%	-11%	-11%	28%
2	hems	216%	382%	320%	175%	205%	210%

Table D 11: ROI Scenario 1.3, LG Chem RESU 6.5, 2020

		Scenario 1.3 – PVP2, BP2					
		ROI over 15 year (LG Chem RESU 6.5, 2020)					
		Configuration 1: Retrofit			Configuration 2: New building		
		Sub-configuration 1: EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	ev, battery, hems	-50%	-47%	-13%	-49%	-47%	-15%
2	ev, hems	154%	257%	273%	125%	167%	161%
		Sub-configuration 2: no EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	battery, hems	-51%	-48%	-14%	-50%	-48%	-16%
2	hems	143%	246%	264%	114%	156%	153%

Table D 12: ROI Scenario 1.3, LG Chem RESU 6.5, 2025

		Scenario 1.3 – PVP2, BP2					
		ROI over 15 year (LG Chem RESU 6.5, 2025)					
		Configuration 1: Retrofit			Configuration 2: New building		
		Sub-configuration 1: EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	ev, battery, hems	-38%	-34%	8%	-36%	-34%	6%
2	ev, hems	154%	257%	273%	125%	167%	161%
		Sub-configuration 2: no EV					
Case	Description	TR1	TR2	TR3	TR1	TR2	TR3
1	battery, hems	-39%	-35%	7%	-37%	-35%	5%
2	hems	143%	246%	264%	114%	156%	153%

Table D 13: Monthly savings for Payback Time calculation, Case 1 Scenario 1.1, C1, TR3

Month \ Year	‘21	‘22	‘23	‘24	‘25	‘26	‘27	‘28	‘29	‘30	‘31	‘32	‘33	‘34	‘35	‘36	‘37
	Monthly Savings (€)																
Jan	56	57	58	59	62	66	69	74	77	82	85	92	96	99	105	107	113
Feb	46	47	48	50	53	57	60	65	68	76	82	90	93	95	100	103	110
Mar	46	47	48	53	59	65	72	79	88	96	106	124	127	133	138	146	151
Apr	33	34	34	39	43	48	55	60	70	76	84	98	102	109	111	119	123
May	24	25	25	29	35	43	49	57	64	74	83	99	107	110	116	121	127
Jun	26	26	27	30	35	42	48	56	62	71	80	96	101	105	111	115	121
Jul	23	24	24	30	35	41	48	54	63	70	80	97	100	107	110	117	120
Aug	23	23	24	30	36	43	51	57	67	75	86	105	110	116	119	127	131
Sep	26	26	27	30	36	41	48	56	62	71	79	96	99	105	110	113	120
Oct	40	41	42	43	50	53	59	65	70	78	85	99	101	106	111	115	120
Nov	52	53	54	56	58	63	64	68	73	75	82	86	92	93	98	102	104
Dec	52	53	55	53	58	60	62	66	68	74	74	82	84	87	92	93	100

Table D 14: Accumulated yearly savings for Payback Time calculation, Case 1 Scenario 1.1, C1, TR3

Accumulated Yearly Savings €																
‘21	**‘22**	**‘23**	**‘24**	**‘25**	**‘26**	**‘27**	**‘28**	**‘29**	**‘30**	**‘31**	**‘32**	**‘33**	**‘34**	**‘35**	**‘36**	**‘37**
447	902	1367	1869	2429	3051	3738	4495	5328	6246	7253	8417	9630	10896	12217	13593	15033

Table D 15: Monthly savings for Payback Time calculation, Case 2 Scenario 1.1, C1, TR3

	Monthly Savings (€)																
Year / Month	**'21**	**'22**	**'23**	**'24**	**'25**	**'26**	**'27**	**'28**	**'29**	**'30**	**'31**	**'32**	**'33**	**'34**	**'35**	**'36**	**'37**
Jan	17	17	9	17	19	19	21	22	23	25	26	28	29	30	31	32	35
Feb	13	13	7	14	14	15	16	18	18	20	21	22	23	24	26	25	28
Mar	19	20	16	21	22	24	24	27	28	29	32	34	36	36	39	41	41
Apr	10	11	9	12	12	14	16	15	19	18	21	22	24	26	25	28	28
May	6	6	6	6	7	9	8	10	10	12	13	14	17	15	17	17	19
Jun	8	8	8	8	8	9	10	12	11	13	14	15	16	17	18	18	20
Jul	6	6	6	8	9	8	11	10	12	12	14	17	16	19	17	20	19
Aug	6	6	5	7	8	8	10	10	12	13	14	17	17	19	18	21	21
Sep	6	6	5	6	8	8	10	11	11	13	13	17	16	18	19	18	20
Oct	13	13	9	13	15	15	17	18	19	20	22	25	25	26	28	29	30
Nov	20	20	15	21	22	23	24	25	27	27	28	31	32	32	34	36	37
Dec	14	14	7	14	16	16	17	18	19	21	21	23	24	25	25	27	28

Table D 16: Accumulated yearly savings for Payback Time calculation, Case 2 Scenario 1.1, C1, TR3

Accumulated Yearly Savings €																
'21	**'22**	**'23**	**'24**	**'25**	**'26**	**'27**	**'28**	**'29**	**'30**	**'31**	**'32**	**'33**	**'34**	**'35**	**'36**	**'37**
138	278	380	527	687	857	1040	1235	1444	1668	1907	2173	2447	2735	3034	3345	3670

Table D 17: : Monthly savings for Payback Time calculation, Case 2 Scenario 1.1, C2, TR3

Year / Month	Monthly Savings (€)																
	‘21	**‘22**	**‘23**	**‘24**	**‘25**	**‘26**	**‘27**	**‘28**	**‘29**	**‘30**	**‘31**	**‘32**	**‘33**	**‘34**	**‘35**	**‘36**	**‘37**
Jan	10	10	10	10	11	11	13	14	14	16	16	19	19	20	21	21	23
Feb	7	7	8	8	8	9	9	11	10	12	13	14	15	15	17	16	18
Mar	13	13	14	14	16	17	17	19	20	21	23	26	26	27	28	30	30
Apr	8	8	8	9	9	10	12	12	14	14	16	18	19	20	20	23	22
May	6	6	6	6	6	8	8	9	9	12	12	13	16	15	16	16	18
Jun	7	8	8	7	8	9	9	11	11	13	13	15	16	16	18	17	19
Jul	5	5	5	7	8	8	10	9	11	11	13	15	15	17	16	18	17
Aug	5	5	5	6	7	7	9	9	11	12	13	16	16	18	17	19	20
Sep	5	5	5	5	7	7	8	9	9	11	12	15	14	16	17	15	18
Oct	8	9	9	10	11	11	12	14	15	16	18	20	21	21	23	23	24
Nov	11	12	12	12	13	14	14	15	17	17	18	20	21	21	22	24	24
Dec	8	8	8	7	9	9	9	10	10	12	11	13	13	13	14	15	16

Table D 18: Accumulated yearly savings for Payback Time calculation, Case 2 Scenario 1.1, C2, TR3

Accumulated Yearly Savings €																
‘21	**‘22**	**‘23**	**‘24**	**‘25**	**‘26**	**‘27**	**‘28**	**‘29**	**‘30**	**‘31**	**‘32**	**‘33**	**‘34**	**‘35**	**‘36**	**‘37**
94	189	287	388	500	620	751	893	1045	1212	1390	1594	1803	2023	2252	2490	2740

Table D 19: Monthly savings for Payback Time calculation, Case 2 Scenario 1.3, C1, TR3

	Monthly Savings (€)																
Year / Month	'21	'22	'23	'24	'25	'26	'27	'28	'29	'30	'31	'32	'33	'34	'35	'36	'37
Jan	14	15	15	15	16	16	18	18	19	20	21	22	23	24	25	26	27
Feb	12	12	13	13	13	14	14	16	16	18	19	19	20	21	23	22	24
Mar	17	18	18	19	20	21	21	23	24	25	27	29	30	30	33	34	34
Apr	9	9	10	10	11	12	13	13	15	15	17	18	19	21	20	23	22
May	6	6	6	6	6	9	8	10	10	12	13	14	17	15	17	17	19
Jun	8	8	8	8	9	9	10	12	11	13	14	15	16	16	18	17	19
Jul	6	6	6	8	9	8	11	10	12	12	14	16	15	18	16	19	18
Aug	6	6	6	6	8	8	10	10	12	13	14	17	17	19	18	21	21
Sep	6	6	7	7	8	8	9	10	9	11	12	14	14	15	16	15	17
Oct	10	11	11	12	12	13	14	15	16	16	18	20	20	21	22	23	23
Nov	17	17	17	17	18	19	19	21	22	22	23	24	26	26	28	29	29
Dec	12	13	13	12	13	14	15	15	16	17	17	19	20	20	21	22	23

Table D 20: Accumulated yearly savings for Payback Time calculation, Case 2 Scenario 1.3, C1, TR3

Accumulated Yearly Savings €																
'21	'22	'23	'24	'25	'26	'27	'28	'29	'30	'31	'32	'33	'34	'35	'36	'37
125	252	381	515	657	809	971	1143	1327	1521	1729	1956	2192	2438	2695	2962	3240

Table D 21: Monthly savings for Payback Time calculation, Case 2 Scenario 1.3, C2, TR3

	Monthly Savings (€)																
Year / Month	**'21**	**'22**	**'23**	**'24**	**'25**	**'26**	**'27**	**'28**	**'29**	**'30**	**'31**	**'32**	**'33**	**'34**	**'35**	**'36**	**'37**
Jan	7	7	8	7	8	8	9	10	10	11	11	13	13	14	15	15	16
Feb	6	6	6	7	7	7	7	9	8	10	10	11	12	12	14	12	15
Mar	10	11	11	11	13	13	13	15	16	17	18	21	21	21	22	24	24
Apr	5	6	6	7	6	8	9	8	11	10	12	13	14	15	14	17	16
May	5	5	5	5	6	8	8	9	9	12	13	14	17	16	17	17	19
Jun	7	7	7	7	8	9	9	11	11	12	13	14	15	16	17	17	18
Jul	5	5	5	7	7	7	9	9	11	10	12	15	14	16	15	17	16
Aug	5	5	5	6	7	7	9	9	11	12	13	17	16	18	18	20	20
Sep	5	5	5	5	6	7	8	9	9	10	11	14	13	15	16	15	17
Oct	6	6	6	7	8	8	8	10	10	11	13	14	14	15	16	17	17
Nov	8	8	8	9	9	10	10	11	12	12	13	14	15	14	15	16	16
Dec	5	5	6	5	6	6	6	7	7	8	8	9	10	9	10	10	11

Table D 22: Accumulated yearly savings for Payback Time calculation, Case 2 Scenario 1.3, C2, TR3

Accumulated Yearly Savings €																
'21	**'22**	**'23**	**'24**	**'25**	**'26**	**'27**	**'28**	**'29**	**'30**	**'31**	**'32**	**'33**	**'34**	**'35**	**'36**	**'37**
76	153	232	314	405	503	609	726	851	987	1134	1301	1474	1655	1844	2040	2245

Appendix E

Table E 1: Appliances Pattern for Scenario 2

Appliance	N	Power Rating (W)	Standby Power (W)	Consumption per Cycle (kWh)	Use (duration, time)	Source
Continuously used						
Internet Router	1	10				(energuide.be, 2020)
Telephone	1	4	2			(energuide.be, 2020)
Refrigerator (A++)	1	24.2				(Coolblue, 2020)
Food Preparation						
Coffee Machine	1	1000			5 minutes, 7-8 5 minutes, 13-14	(energuide.be, 2020)
Toaster	1	1200			3 minutes, 7-8	(energuide.be, 2020)
Kettle	1	1300			3 minutes, 7-8 3 minutes, 17-18	(energuide.be, 2020)
Microwave oven	1	1150			12 minutes, 7-9 12 minutes, 12-1 (excl. Sat) 12 minutes, 19-21	(energuide.be, 2020)
Cooker Hood (A)	1	75			2 hours, 12-14 (excl. Sat) 2 hours, 19-21	(energuide.be, 2020)
Induction hob	1	1600			36 minutes, 7-9 2 hours, 12-14 (excl. Sat) 2 hours, 19-21	(energuide.be, 2020)
Electric Oven	1	1900			36 minutes, 19-21	(energuide.be, 2020)
Cleaning						
Iron	1	900			30 minutes, 7-8	(energuide.be, 2020)
Washing machine (A+++)	1			0.80	104 cycles/year, 2 hours per cycle (Mo,Thu) 0-2	(Coolblue, 2020)
Dryer (A++)	1			0.96	104 cycles/year, 2 hours per cycle (Mo,Thu) 0-2	(Coolblue, 2020)
Vacuum Cleaner	1	800			2 hours, 12-14 (Mo, Wed, Fri)	(energuide.be, 2020)
Dishwasher (A++)	1			0.94	3 cycles/week, 2 hours/cycle (Tu,Fr,Su), 2-4	(Coolblue, 2020)
ICE						
LED TV	1	62	0.0002		16 hours, 8-24 (excl Sat) Sat: 2 hours: 22-24	(energuide.be, 2020)
Laptop	1	60			4 hours, 0-4	(energuide.be, 2020)
Printer	1	350			9.6 minutes, 16-17	(energuide.be, 2020)
Lighting						
Low Energylight bulbs	23	12			6-9 (100%), 9-16 (10%), 16-18 (50%), 18-0 (100%)	(GCEA, 2020)

Table E 2: Electricity Bill Scenario 2.1

		Scenario 2.1 – PVP1, BP1		
		Electricty Bill over 15 years €		
		Configuration 1: Retrofit		
		Sub-configuration 1: EV		
Case	Description	TR1	TR2	TR3
0	ev	32289	30460	32240
1	ev, battery, hems	24795	22862	21206
2	ev, hems	31286	29486	31065
		Sub-configuration 2: no EV		
Case	Description	TR1	TR2	TR3
0		25539	24240	26600
1	battery, hems	19539	17888	15566
2	hems	24639	23267	25425

Table E 3: Electricity Bill Scenario 2.2

		Scenario 2.2 – PVP1, BP2		
		Electricty Bill over 15 years €		
		Configuration 1: Retrofit		
		Sub-configuration 1: EV		
Case	Description	TR1	TR2	TR3
0	ev	32289	30460	32240
1	ev, battery, hems	27322	25178	23718
2	ev, hems	31286	29486	31065
		Sub-configuration 2: no EV		
Case	Description	TR1	TR2	TR3
0		25539	24240	26600
1	battery, hems	20845	19218	18078
2	hems	24639	23267	25425

Table E 4: Electricity Bill Scenario 2.3

		Scenario 2.3 – PVP2, BP2		
		Electricty Bill over 15 years €		
		Configuration 1: Retrofit		
		Sub-configuration 1: EV		
Case	Description	TR1	TR2	TR3
0	ev	40266	38226	40387
1	ev, battery, hems	36767	34599	33086
2	ev, hems	39535	37447	39373
		Sub-configuration 2: no EV		
Case	Description	TR1	TR2	TR3
0		33516	32007	34747
1	battery, hems	30218	28580	27446
2	hems	32857	31228	33733

Table E 5: ROI Scenario 2.1, TESLA Powerwall 2.0, 2020

		Scenario 2.1 – PVP1, BP1		
		ROI over 15 years (TESLA Powerwall 2.0, 2020) €		
		Configuration 1: Retrofit		
Sub-configuration 1: EV				
Case	Description	TR1	TR2	TR3
1	ev, battery, hems	-27%	-26%	7%
2	ev, hems	25%	22%	47%
Sub-configuration 2: no EV				
Case	Description	TR1	TR2	TR3
1	battery, hems	-42%	-38%	7%
2	hems	13%	22%	47%

Table E 6: ROI Scenario 2.1, TESLA Powerwall 2.0, 2025

		Scenario 2.1 – PVP1, BP1		
		ROI over 15 years (TESLA Powerwall 2.0, 2025) €		
		Configuration 1: Retrofit		
Sub-configuration 1: EV				
Case	Description	TR1	TR2	TR3
1	ev, battery, hems	0%	1%	47%
2	ev, hems	25%	22%	47%
Sub-configuration 2: no EV				
Case	Description	TR1	TR2	TR3
1	battery, hems	-20%	-16%	47%
2	hems	13%	22%	47%

Table E 7: ROI Scenario 2.2, LG Chem RESU 6.5, 2020

		Scenario 2.2 – PVP1, BP2		
		ROI over 15 years (LG Chem RESU 6.5, 2020) €		
		Configuration 1: Retrofit		
Sub-configuration 1: EV				
Case	Description	TR1	TR2	TR3
1	ev, battery, hems	-45%	-42%	-6%
2	ev, hems	25%	22%	47%
Sub-configuration 2: no EV				
Case	Description	TR1	TR2	TR3
1	battery, hems	-48%	-45%	-6%
2	hems	13%	22%	47%

Table E 8: ROI Scenario 2.2, LG Chem RESU 6.5, 2025

		Scenario 2.2 – PVP1, BP2		
		ROI over 15 years (LG Chem RESU 6.5, 2025) €		
		Configuration 1: Retrofit		
Sub-configuration 1: EV				
Case	Description	TR1	TR2	TR3
1	ev, battery, hems	-32%	-27%	17%
2	ev, hems	25%	22%	47%
Sub-configuration 2: no EV				
Case	Description	TR1	TR2	TR3
1	battery, hems	-35%	-31%	17%
2	hems	13%	22%	47%

Table E 9: ROI Scenario 2.3, LG Chem RESU 6.5, 2020

		Scenario 2.3 – PVP2, BP2		
		ROI over 15 years (LG Chem RESU 6.5, 2020) €		
		Configuration 1: Retrofit		
Sub-configuration 1: EV				
Case	Description	TR1	TR2	TR3
1	ev, battery, hems	-61%	-60%	-19%
2	ev, hems	-9%	-3%	27%
Sub-configuration 2: no EV				
Case	Description	TR1	TR2	TR3
1	battery, hems	-64%	-62%	-19%
2	hems	-18%	-3%	27%

Table E 10: ROI Scenario 2.2, LG Chem RESU 6.5, 2025

		Scenario 2.3 – PVP2, BP2		
		ROI over 15 years (LG Chem RESU 6.5, 2025) €		
		Configuration 1: Retrofit		
Sub-configuration 1: EV				
Case	Description	TR1	TR2	TR3
1	ev, battery, hems	-52%	-50%	0%
2	ev, hems	-9%	-3%	27%
Sub-configuration 2: no EV				
Case	Description	TR1	TR2	TR3
1	battery, hems	-55%	-53%	0%
2	hems	-18%	-3%	27%

Appendix F

Table F 1: Profit Calculation before the Self-consumption maximisation proposal

Getallen in euro	Winst en verlies Q1-Q3 2019		Winst en verlies 2019		Profit and loss 2020		Profit and loss 2021		Profit and loss 2022		Profit and loss 2023	
Revenues		#		#		#		#		#		#
Energy neutral homes	€ 67.767	0	€ 137.949	12	€ 1.185.000	79	€ 5.782.500	386	€ 22.575.000	1.505	€ 110.872.500	7.392
Energy plans	€ -	1	€ 3.463	8	€ 17.479	47	€ 81.446	219	€ 335.455	902	€ 1.245.496	3.349
	€ -	1	€ 400	1	€ -	0	€ -	0	€ -	0	€ -	0
Service contracts	€ -	0	€ 100	3	€ 2.413	32	€ 16.678	178	€ 72.231	178	€ 316.959	3.037
Total revenues	€ 67.767		€ 141.912		€ 1.204.893		€ 5.880.624		€ 22.982.686		€ 112.434.955	
Purchases												
Purchases for home conversions	€ 57.482		€ 101.833		€ 983.550		€ 4.510.350		€ 16.931.250		€ 83.154.375	
Purchases for service	€ -		€ 44		€ 584		€ 4.036		€ 17.480		€ 76.704	
Total purchases	€ 57.482		€ 101.877		€ 984.134		€ 4.514.386		€ 16.948.730		€ 83.231.079	
Gross margin	€ 10.285	15,2%	€ 40.034	28,2%	€ 220.759	18,3%	€ 1.366.238	23,2%	€ 6.033.956	26,3%	€ 29.203.876	26,0%
Expenses												
Personnel	€ 33.615		€ 76.876		€ 418.703		€ 1.051.777		€ 3.892.916		€ 9.099.312	
General costs	€ 17.630		€ 40.525		€ 76.893		€ 645.351		€ 1.853.780		€ 5.393.439	
Total expenses	€ 51.245		€ 117.401		€ 495.595		€ 1.697.128		€ 5.746.696		€ 14.492.751	
EBITDA	€ -40.960		€ -77.366		€ -274.837	-22,8%	€ -330.890	-5,6%	€ 287.260	1,2%	€ 14.711.124	13,1%
Depreciation	€ -		€ 2.833		€ 30.353		€ 84.927		€ 193.180		€ 439.693	
EBIT	€ -40.960		€ -80.200		€ -305.190		€ -415.817		€ 94.080		€ 14.271.431	
Intrest received	€ -		€ -		€ -		€ -		€ -		€ -	
Intrest paid	€ 2.072		€ 2.699		€ 2.189		€ 1.679		€ 1.169		€ 659	
Tax	€ -		€ -		€ -		€ -		€ 18.582		€ 3.557.693	
Net result	€ -43.031		€ -82.898	-60,1%	€ -307.379	-25,9%	€ -417.496	-7,2%	€ 74.329	0,3%	€ 10.713.079	9,7%

Table F 2: Profit Calculation after the Self-consumption maximisation proposal

Getallen in euro	Winst en verlies Q1-Q3 2019		Winst en verlies 2019		Profit and loss 2020		Profit and loss 2021		Profit and loss 2022		Profit and loss 2023	
Revenues		#		#		#		#		#		#
Energy neutral homes	€ 67.767	€ -	€ 137.949	€ 12	€ 1.185.000	€ 79	€ 5.859.600	€ 386	€ 22.876.000	€ 1.505	€ 112.350.800	€ 7.392
Energy plans	€ -	€ 1	€ 3.463	€ 8	€ 17.479	€ 47	€ 81.446	€ 219	€ 335.455	€ 902	€ 1.245.496	€ 3.349
	€ -	€ 1	€ 400	€ 1	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Service contracts	€ -	€ -	€ 100	€ 3	€ 2.413	€ 32	€ 16.678	€ 178	€ 72.231	€ 178	€ 316.959	€ 3.037
Total revenues	€ 67.767		€ 141.912		€ 1.204.893		€ 5.957.724		€ 23.283.686		€ 113.913.255	
Increase					0%		1,3%		1,3%		1,3%	€ 1.478.300
Purchases												
Purchases for home conversions	57482		101833,33		983550		4510350		€ 16.931.250		83154375	
Purchases for service	0		44		584		4036		17480		76704	
Total purchases	€ 57.482		€ 101.877		€ 984.134		€ 4.514.386		€ 16.948.730		€ 83.231.079	
Gross margin	€ 10.285	15,2%	€ 40.034	28,2%	€ 220.759	18,3%	€ 1.443.338	24,2%	€ 6.334.956	27,2%	€ 30.682.176	26,9%
Gross margin Increase								1,0%	30100000,0%	1,0%	147830000,0%	1,0%
Expenses												
Personnel	€ 33.615		€ 76.876		€ 418.703		€ 1.051.777		€ 3.892.916		€ 9.099.312	
General costs	€ 17.630		€ 40.525		€ 76.893		€ 645.351		€ 1.853.780		€ 5.393.439	
Total expenses	€ 51.245		€ 117.401		€ 495.595		€ 1.697.128		€ 5.746.696		€ 14.492.751	
EBITDA	€ -40.960		€ -77.366		€ -274.837	-22,8%	€ -253.790	-4,3%	€ 588.260	2,5%	€ 16.189.424	14,2%
Depreciation	€ -	€ -	€ 2.833		€ 30.353		€ 84.927		€ 193.180		€ 439.693	
EBIT	€ -40.960		€ -80.200		€ -305.190		€ -338.717		€ 395.080		€ 15.749.731	
Intrest received	€ -		€ -		€ -		€ -		€ -		€ -	
Intrest paid	€ 2.072		€ 2.699		€ 2.189		€ 1.679		€ 1.169		€ 659	
Tax	€ -		€ -		€ -		€ -		€ 18.582		€ 3.557.693	
Net result	€ -43.031		€ -82.898	-60,1%	€ -307.379	-25,9%	€ -340.396	-5,8%	€ 375.329	1,6%	€ 12.191.379	10,9%
Increase net Result							€ 77.100	1,4%	€ 301.000	1,3%	€ 1.478.300	1,2%

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