Design and Product Development of a Residential Energy Storage System

Rafael López Pizarro

Thesis to obtain the Master of Science Degree in

Energy Engineering and Management

Supervisors: Prof. Maria de Fátima Grilo da Costa Montemor

Dr. Guillaume Jeangros

Examination Committee

Chairperson: Prof. Duarte de Mesquita e Sousa

Supervisor: Prof. Maria de Fátima Grilo da Costa Montemor

Member of the Committee: Prof. Sónia Maria Nunes dos Santos Paulo Ferreira Pinto

October 2018

Acknowledgments

Acknowledgments of this work are for all the people that helped in making it possible.

First of all, I would like to thank to Mr. Guillaume Jeangros, CEO and co-founder of Azolis, for trusting me in the challenge of developing a product and a business plan that allows the company to expand their business into a new field. Especial thanks to my co-workers, who helped me in the integration to its culture and way of working since the beginning, even though some of them did not speak English and I did not speak French or Darija in the first moments.

Acknowledgements as well for my academic supervisor Fátima Montemor, who accepted to guide my vision on the idea, whose strong scientific sight helped in keeping the document in the right standards of an academic essay and whose advices were key for focusing my work on bringing value to the scientific and academic community.

Especial thanks to InnoEnergy for supporting my Master's Degree, for giving me the chance on forming myself as an engineer specialised in renewable energy with a lot of insights on the business side, and for giving me the opportunity to belong to a network of gamechangers that are willing to fight against climate change and leave their footprint on it.

Shoukrane to Morocco and all the people I have met on my way. I had the opportunity to live immersed inside another culture, to understand its significance to the people who come from there, people who helped in broadening more my global mind-set on how people perceive the world and life. Thanks for all the experiences I lived in there, for both the good and the bad.

Por supuesto, gracias a la madre que me parió y a mi padre, por inculcarme valores desde bien pequeñito y formar, en parte, la persona que hoy soy; por apoyarme en cada momento y en cada decisión tomada, sobre todo en los últimos cuatro años que llevo fuera de España de país en país, aunque les pesara. El estar fuera tanto me ha hecho valorar más todo el cariño que me dais, mamá y papá.

Last acknowledgment to my close-friends who inspire and motivate me every day, in both the bad and the good moments, and to the people that left a footprint in the person I am today.

Resume

This document is the master thesis of the author enrolled inside the M.Sc. in Energy Engineering and Management by Instituto Superior Técnico (IST), Universidade de Lisboa. It is accounted also as master thesis for the M.Sc. in Energy Engineering by Universitat Politècnica de Catalunya (UPC), as part of the international double M.Sc. in Renewable Energy by InnoEnergy, labelled by the European Institute of Innovation & Technology (EIT).

The thesis is an internship-based work developed at Azolis, a small enterprise based in Casablanca (Morocco), whose main activity is the distribution and installation of solar PV panels and HSW systems around Africa and Middle East Asia, mainly for industrial applications. Basing the work on the company's idea of expanding the business to storage solutions, the author performs the essentials of a project management for the development and design of an innovative and differentiated energy storage solution for residential application.

Please note that the actual version has many data hidden as per confidentiality agreements.

Abstract

This document focuses on the project management of the development and design of an energy storage system for residential application. The work conducted is the practice of initiating, analysing, planning, executing and controlling the main aspects involved on a project for the expansion of a business into a new field through the development of a product. All the thinking process, idea generation, decision making and strategy definition is meticulously developed and argued for a better understanding of the lector.

The document shows how all the stages needed to develop and design a competitive product are performed, and how to implement this product in the market through a consistent business plan. The result of this work is an outstanding modular all-in-one battery system that incorporates an innovative BMS unique in the world that extends the lifespan of the batteries, preserving its factory conditions and thus, performing at an optimized level. The financial results and business plan suggest a rapid entry to the market with very profitable results from the 3rd year of commercialization of the RESS.

Keywords: Energy storage, Product development, Project Management, Innovation, Business, Residential application.

Abstrato

Este documento enfoca o gerenciamento de projetos de desenvolvimento e projeto de um sistema de armazenamento de energia para aplicações residenciais. O trabalho realizado é a prática de iniciar, analisar, planejar, executar e controlar os principais aspectos envolvidos em um projeto para a expansão de um negócio em um novo campo através do desenvolvimento de um produto. Todo o processo de pensamento, geração de ideias, tomada de decisão e definição de estratégia é meticulosamente desenvolvido e defendido para uma melhor compreensão do leitor.

O documento mostra como todas as etapas necessárias para desenvolver e projetar um produto competitivo são executadas e como implementar esse produto no mercado por meio de um plano de negócios consistente. O resultado deste trabalho é um excelente sistema de bateria tudo-em-um modular que incorpora um inovador BMS único no mundo que prolonga a vida útil das baterias, preservando suas condições de fábrica e, assim, atuando em um nível otimizado. Os resultados financeiros e o plano de negócios sugerem uma entrada rápida no mercado com resultados muito lucrativos a partir do 3º ano de comercialização do RESS.

Palavras-chave: Armazenamento de energia, desenvolvimento de produtos, gerenciamento de projetos, inovação, negócios, aplicação residencial.

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Abbreviations

AC – Alternating Current

BMC – Business Model Canvas

BMS – Battery Management System

C-rate – Rate at which a battery is discharged relative to its maximum capacity

DC – Direct Current

EMS – Energy Management System

ESS – Energy Storage Solution

EU – European Union

GCIP – Global Cleantech Innovation Program

GDP – Gross Domestic Product

GHG – GreenHouse Gas

IRESEN – Institute Research Energy Solaire et Energies Nouvelles

LCOE – Levelized Cost Of Electricity

MPPT – Maximum Power Point Tracking

MVP – Minimum Viable Product

PV – Photovoltaic

R&D – Research and Development

RESS – Residential Energy Storage Solution

ROI – Return on Investment

SAM – Served Addressable Market

SOC – State Of Charge (battery)

SOH – State Of Health (battery)

SOL – State Of Life (battery)

TAM – Total Addressable Market

USA – United States of America

1. Introduction

Context and motivation

During the last decades, climate change concern has been increasingly inculcated in society until it has become a reality. The planet is now entering in a point of no return caused (or highly accelerated) by human activity. Part of the population believes the duty is on politicians and the regulation they establish, that this is outside their control. Even still some small lost part of society denies its evidence. The reality is that climate change is on every one of us and it is happening.

Technology advancement in renewable energy is driving down the cost of clean energy, making it affordable to a big percent of the population and reaching grid parity in some cases. Electricity prices are increasing yearly, and more people is now willing to install PV panels in their rooftop. However, the PV production and household consumption profiles only match in a 35% ratio on average, and feed-in-tariff prices went down to ridiculous levels. Therefore, it is time now for energy storage. By storing the energy from the PV panels, the user can harness all the “free” and clean energy coming from its rooftop installation, matching their consumption on rates up to 85%.

The main barrier for dynamiting the growth of the sector is that currently no RESS leads to a profitable investment with a return on it. Nonetheless, many people are already prioritizing the value of using green energy and become independent from the mix of energy from the grid, composed by many GHG ways of production. The market is increasing almost exponentially, and the race for companies to create the first RESS that provides a payback time to the customer is a fierce competition.

Objectives

In this context, it has been created the opportunity to fully develop a RESS starting from zero, analysing the market and revising all the items and possibilities that can be improved, and studying where to implement economic efforts in order to achieve these results. All this, from the flexibility that a start-up offers in the development of the management of a project. This work is exposed in this document, consisting in the design and development of a RESS from a project management point of view. The objectives of the work are defined as follows:

1. To design and develop the integration of an innovative RESS that can provide differentiation and added values to the customer with regard to the market.
2. To define and implement the first steps of an effective business model and business strategy that allows a successful marketing and launch of the product into the market.
3. To understand and give evidence on why now is the moment to invest and why to do it in this market.
4. To understand all the process behind the management of a project, evaluating all the idea generation, decision making and strategy definition developed.

Contextualization – Business Case & Original contributions

It was the beginning of March 2018 when I arrived to Morocco to develop an ambitious project of developing a storage system for residential application, that would be afterwards the object of my academic Master dissertation. The first day in the office, in Casablanca, the CEO of the company started to introduce me the team, installations and warehouse of the office.

Meanwhile he was presenting to me the different functions or departments of the 9 employees in the bureau, he was drawing a scheme with the office's distribution. Suddenly, he drew a circle out of everything and told me: "…and you are here, in charge of this project". Surprised, I asked him to clarify exactly what he meant. "You will be the person who will take care to develop and manage both the product and the project. Every thinking process, decision making and strategy definition will depend on you, and at the end I will have the last word based in what you present to me. You will have another intern at your disposal that will help in the sourcing and mailing, but it will be you the chief project." The only work done by that moment was the idea of performing a storage system for residential application, and some preliminary contacts to develop partnerships with the companies currently in charge of the EMS, assembly and aesthetical design, together with some meeting with IRESEN (Institute Research Energy Solaire et Energies Nouvelles) for funding intentions; everything else remained to be done.

The object of this Contextualization section, therefore, is to state that every finding, idea generation, decision making, strategy definition and work developed in the course of this dissertation is **original contribution** from its **author** (if not stated otherwise), performing the position of **chief project manager** and **product developer**, always with the final approval of the CEO and founder of Azolis.

2. State of the art of residential storage systems

In this section, the key components and possible configurations of a residential storage system are presented, from different battery chemistries and inverter typologies, to management of the batteries and smart functioning, passing from the different coupling possibilities of the system.

In the residential energy storage sector, batteries are combined mainly with PV panels, so households can store their solar energy and increase the rates of self-consumption, maximizing the profitability of their installation. Apart from batteries, which is the main component of the installation, the system also needs an inverter, a Battery Management System (BMS) and Energy Management System (EMS).

The possibilities in selecting the typology and features of every component are wide, and depending of which characteristics and specifications are chosen, the system configuration can be very different. It still remains unclear which one leads to more profitable consumer investment. Indeed, even system configurations that can be considered as optimal, do not give the customer a payback on the investment before the lifespan of the battery comes to an end. Hereafter, every component of a residential storage system is briefly explained.

2.1. Battery

Batteries are the key component of the system, the ones in charge to store the energy. In residential storage systems, Lithium-ion batteries are widely extended, being the main battery chemistry in the sector. Since Sony commercialized the first Li-ion battery in 1991 [1], this chemistry has become the most promising and fastest growing in the market. In Figure 2.1, we can see how this chemistry have overcome any other. The sizes of those batteries in the market goes from sizes at around 1kWh to 20kWh, offering a wide energy choice to the customer, depending on its needs. Also, latest developments have come out with high voltage batteries, working at around 400V in order to minimize losses. But which characteristics make Lithium-ion superior to other technologies?

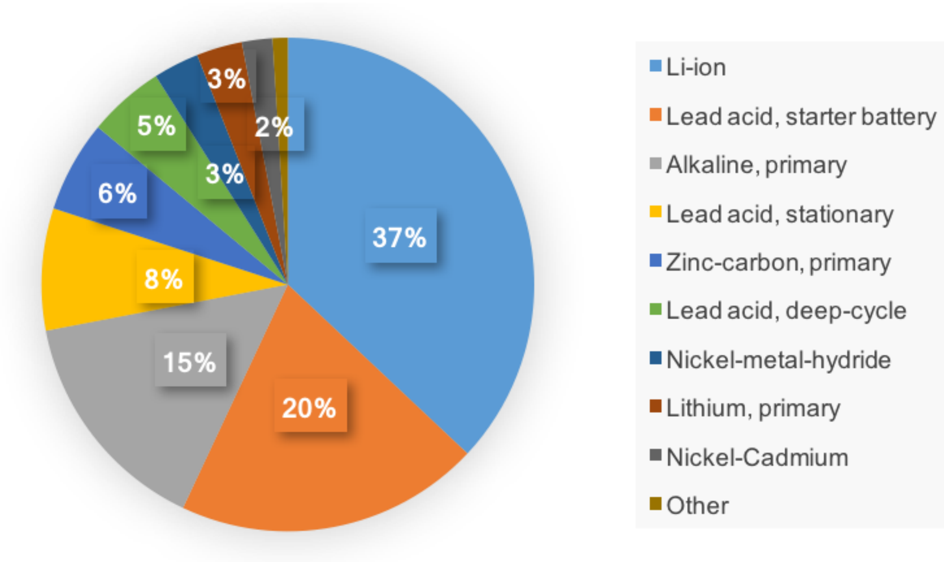


Figure 2.1. Revenue contributions by different battery chemistries in the global market. [1]

The cathode consists of Lithium metal oxide, the anode is made of porous carbon (graphite) and the ionic conductor is the electrolyte. Lithium is the lightest of all metals, has the highest specific energy per weight and the lowest electrochemical reduction potential. On the other hand, graphite is the most common carbon material, thus inexpensive, and provides a flatter discharge curve and long-term cycle stability. In addition, Li-ion are low-maintenance batteries, an advantage that just few chemistries can claim, and their self-discharge rate is less than in half of nickel based chemistries. With technology moving forward rapidly, new families of Li-ion using graphene will improve a lot their performance, and the costs of these kind of batteries are dropping exponentially in the last years thanks to the market demand. Table 2.1 summarises the advantages and limitations of these kind of batteries.

Advantages	High specific energy
	Long cycle and extended shelf-life; free maintenance
	High capacity, low internal resistance, good coulombic efficiency
	Simple charge algorithm and reasonable short charge times
	Low self-discharge (less than half nickel based batteries)
Limitations	Requires protection circuit to prevent thermal runaway if stressed
	Degrades at high temperature and when stored at high voltage
	Transportation regulations required when shipping in large quantities

Table 2.1. Advantages and limitations of Lithium-ion batteries. [1]

Within Li-ion batteries, there are many typologies depending on their active materials. The choice of the combination of the materials in the cathode, will determine the specific energy and power, lifespan, safety, performance and cost. The following figure shows the characteristics of the most common types of Li-ion batteries.

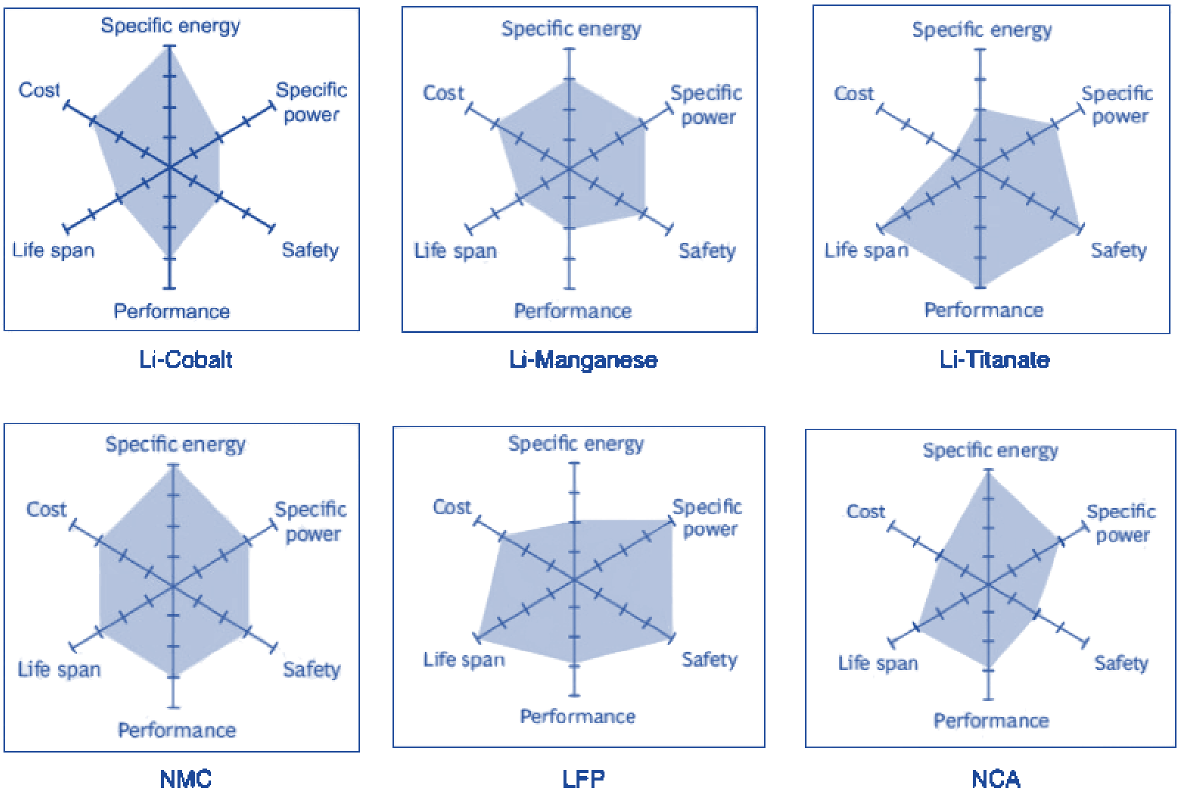


Figure 2.2. Snapshot of average Li-ion type batteries.

The most common types used in residential storage are Lithium Iron Phosphate **LFP** ($LiFePO_4$) and Lithium Nickel Manganese Cobalt Oxide **NMC** ($LiNiMnCoO_2$), followed by Lithium Nickel Cobalt Aluminium Oxide **NCA** ($LiNiCoAlO_2$). Their high safety, performance, specific energy and lifespan make them very suitable for this application. Li-titanate is a promising technology, but more efforts in increasing specific energy and reducing cost must be done. NMC is the newest technology and one of the most promising ones, since it is the technology with fastest cost reduction and improvement of performance. Its safety is supposed to be lower than LFP, but because the technology is not as mature as the last one; theoretically they both reach similar levels of safety. On the other hand, LFP chemistry offers the longest lifespan in the market, assuring 3000 cycles above 80% of useful capacity, in front of the 2000-2500 cycles offered by NMC and NCA at same capacity.

Other types of batteries that some companies are investing in for residential storage are flow batteries, aqueous hybrid ion or lead crystal, but their performance, cost and/or lifespan are not as good as Li-ion batteries yet.

2.2. Inverter

The inverter is the other key component of the residential storage system. Depending on its typology, the system will be coupled in one way or another and will offer added features or basic ones. In a residential storage installation, energy must be regulated DC/DC to charge the batteries, and convert it from DC to AC to delivery energy into the house, either if it is coming from the batteries or directly from the PV array. Depending on the type of inverter chosen, the configuration of the system will be DC coupled, AC coupled or hybrid.

DC coupled systems use solar charge controller (also known as solar regulators) to charge batteries directly from the PV panels. Then, a battery inverter is used to convert this power into AC, as Figure 2.3shows. These systems have a very high efficiency to charge the battery, but when it comes to the global performance, the efficiency goes only up to 90% due to conversion DC-DC-AC. Nonetheless, they are a bit obsolete for residential storage, since the MPPT tracker normally works with string voltages up to 150V, compared to grid-tie solar inverters that work in ranges from 150 to 600V. Therefore, these systems are suitable for small applications up to 3kWh.

Figure 2.3. Diagram of a DC coupled system. Source: own.

AC coupled systems use a solar inverter coupled to a multi-mode inverter or inverter/charger to charge and discharge the battery. These systems are more suitable for residential storage, since solar inverters work with high DC voltages up to 600V and larger systems can be installed. In the last years, AC Lithium-ion batteries have been developed and the multi-mode inverter or inverter/charger is now included inside the battery box, together with the BMS. Example of this type of battery is the Tesla Powerwall 2, which will be discussed in the section of competitors' analysis.

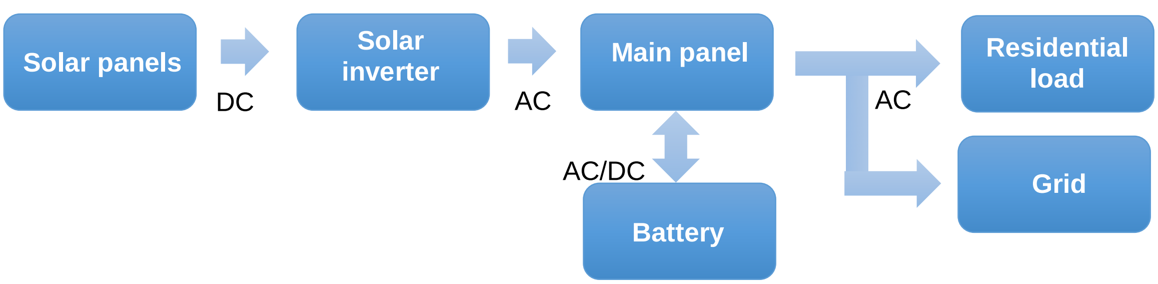


Figure 2.4. Diagram of a AC coupled system. Source: own

Hybrid systems or **all-in-one systems** are built around a hybrid inverter. This device incorporates the functions of the high voltage MPPT tracker/s, solar controller and battery inverter/charger in one plug and play unit. That is why this configuration is also called all-in-one unit. It offers a very simplified installation and good overall performance. One of the advantages of using this system, is that it can be installed either in new or existing installations. If in the solar installation there is an already existing solar inverter, it can be connected to the hybrid in one of the AC entries, and if the installation is new, no solar inverter is needed in between the PV array and the hybrid inverter.

Figure 2.5 shows the diagram of this configuration. Hybrid inverters may come with smart algorithm (EMS) that optimizes the whole functioning of the system, depending on the consumption profiles of the household and the available energy from PV panels.

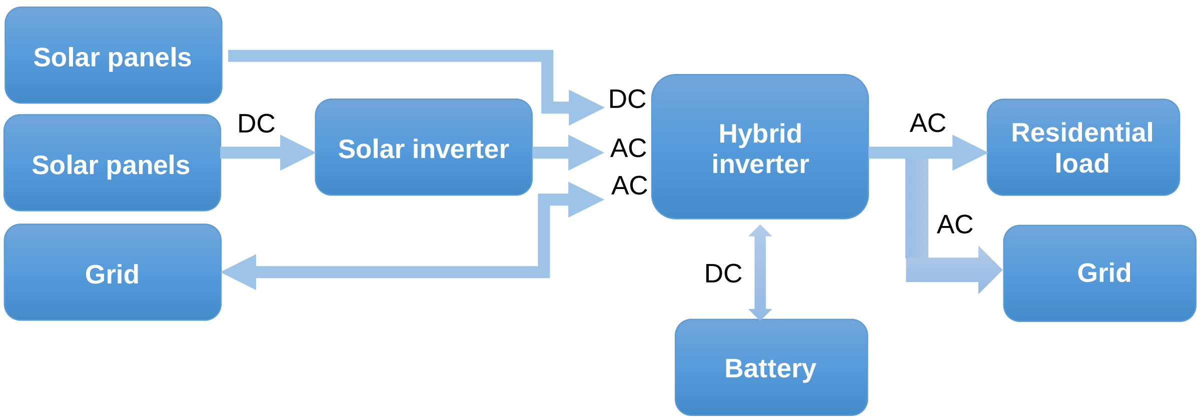


Figure 2.5. Diagram of all-in-one system configuration. Source: own.

2.3. Battery Management System (BMS)

The BMS has two main differentiating functions/parts: to ensure the safety of the battery's performance and the balancing of the cells.

Regarding the safety part, it must ensure that the cells of a battery operate within their rated specifications, so to say, it is the component in charge of the safety of the battery's performance. Its main functions regarding the protection part are summarised in the next points:

- Cell state monitoring, measuring individual cell parameters, such as voltage, peak current and temperature.
- To warn about anomalies in the functioning of the cells or to shut down the functioning of the battery in case of failure to avoid further damages or accidents.
- Control and limiting of charge and discharge currents.
- Thermal management of the cells.
- Estimation of parameters as State Of Charge (SOC), State Of Health (SOH) and State of Life (SOL) of the battery. Also the communication of these parameters to the inverter, so the inverter knows at any time the state of the battery and how much energy stored is available.

In regards of the balancing part, depending on its sophistication, the BMS will make an impact in more or less degree on the battery's performance, expanding up to certain level its lifespan. Normally the cells on a battery age differently, because of many factors such as temperature stress or the nature of the chemicals of the cell. Because of that, the useful capacity of every cell varies during time, decreasing differently. The balancing system of the BMS will determine how the cells of a battery ages over a high period of cycles. Ideally, all of them shall be charged and discharge synchronously, sharing exactly the same amount of voltage.

There are many typologies and methodologies on cell balancing. The typologies can be mainly divided in passive and active balancing.

- Passive balancing. It acts by removing the surplus of energy of the most charged cells through a resistor, until the lowest charged cells match them, levering the state of charge of all the cells. The resistor element can be fixed or switched, offering two more typologies for passive balancing.
- Active balancing. It acts by transferring energy from the most charged cells to the less charged ones, ensuring a more continuous and optimized level of balance in between the charge/discharge of the cells, but more sophisticated and thus, expensive. Depending on the active element used to store the energy, active balancing can be divided in transformer/inductor base, capacitor base or converter base.

A comprehensive review on the different balancing technologies is given in the literature [2], and the main pros and cons of each one are summarized in the following table [3]:

Balancing technique	Balancing technique	Pros	Cons
Passive	• Cell-to-heat (one bleeding resistor and switch per cell)	• Very simple • Very cheap	• 0% efficiency • Slow (limited by the maximum allowable dissipated power on board
Active	• Module-to-cell (charge transfer from a battery module to a single cell by means of a galvanic isolated DC/DC converter)	• Relatively simple • Good efficiency • Fast	• Switch network • High isolation voltage of the DC/DC
Active	• Cell-to-cell distributed (charge transfer from adjacent cells)	• Moderate efficiency • Moderately fast	• Bulky • Complex control
	• Cell-to-cell shared (charge transfer from cell A to tank, then from tank to cell B)	• High efficiency • Fast	• Switch network
Active	• Cell module bypass (a cell/module disconnection from the current path	• High balancing efficiency • Very fast and flexible	• High current switches • Complex to implement • Decrease battery efficiency during operation

Table 2.2. Comparison in between different balancing methods. [3]

2.4. Energy Management System (EMS)

The Energy Management System (EMS) is the component of the installation in charge of the optimization of the flows of energy. As stated before, some expensive hybrid inverters may come with some EMS integrated, but with basic functionalities. Integrating an external EMS can multiply the optimization and maximize the ROI of the installation. In residential energy storage, the software of an EMS can leverage advance learning algorithms to anticipate dispatch energy strategies by predicting the weather forecast regarding the location. With its learning machine engineering, it can study the usual consumption profile of a household and hold stored energy for high consumption daily periods, or dispatch it when electricity prices are more expensive. It also allows the customer to have remote control on the system through app interfaces, optimizing it as the customer wishes, and provides to the company in charge of the residential storage installation to advice to the customer about further savings by optimizing the energy system.

Nonetheless, not all residential storage applications include an EMS, as it is still unclear if the cost of it makes a real impact in the ROI of the system.

3. Market analysis and concept development

In this section, the market of Residential Energy Storage Systems (RESS) will be analysed, identifying which are the pain of the customers that makes this sector so demanding nowadays, the expected trends for the following years in terms of market volume, and which countries are leading the growth of the market. Afterwards, an analysis of the main competitors that offer residential battery systems will be performed, deeply studying weaknesses and possible improvements in what do they offer, to better understand how a RESS is performing. Finally, regarding the market research and taking advantage of competitors' analysis, the idea of what this project is aiming to develop will be realized.

3.1. RESS market status and forecasts

Lithium-ion batteries are being considered as key for energy storage in a wide range of applications, such as Electric Vehicles (EVs), grid services, commercial and industry buildings or residential energy storage. Technology advancements, social and environmental needs and market demand are making these markets increase exponentially, as the transition to renewable energy is moving forward.

One of the main problems or pains for the customer is that household's consumption profiles usually do not match PV production profiles. Batteries allow households to store the energy from their PV installation and use it when the consumption is high out of sunny hours, maximizing the profitability of their installation. Figure 3.1 shows the self-consumption rate potential without storage in key EU markets, which is relatively low

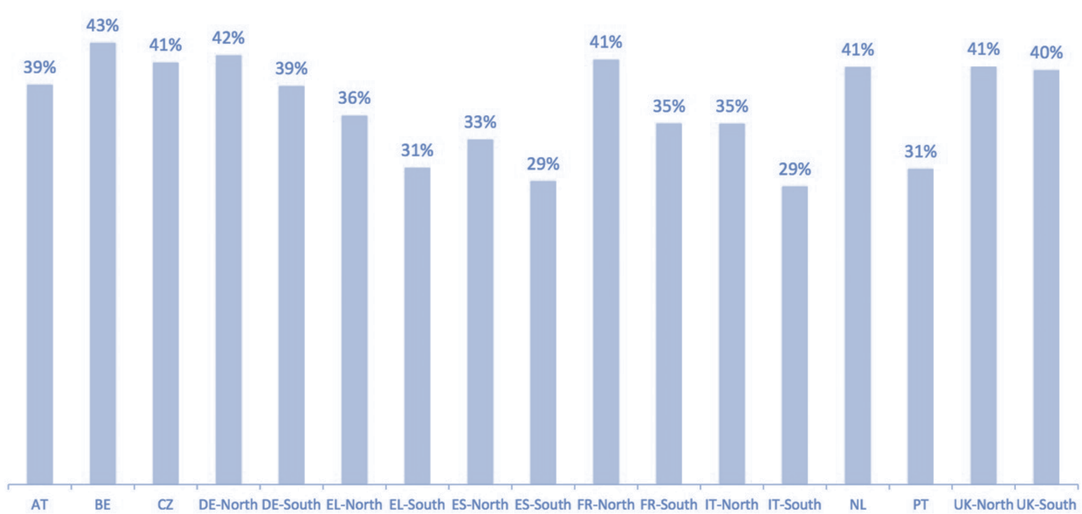


Figure 3.1. Residential self-consumption rate potential without storage in Europe. [4]

In a context of increasingly electricity prices, PV technology reaching grid parity, decreasingly cost of generating solar energy and decreasingly feed-in-tariff subsidies, energy storage solutions (ESS) are becoming financially more appealing for households. This trend is expected to grow stronger over the time. Figure 3.2 illustrates how this tendency evolved since the beginning of the century in Germany. As it can be observed, the gross domestic electricity price is higher than the average feed-in-tariff price, and it is double than the cost of a residential PV system.

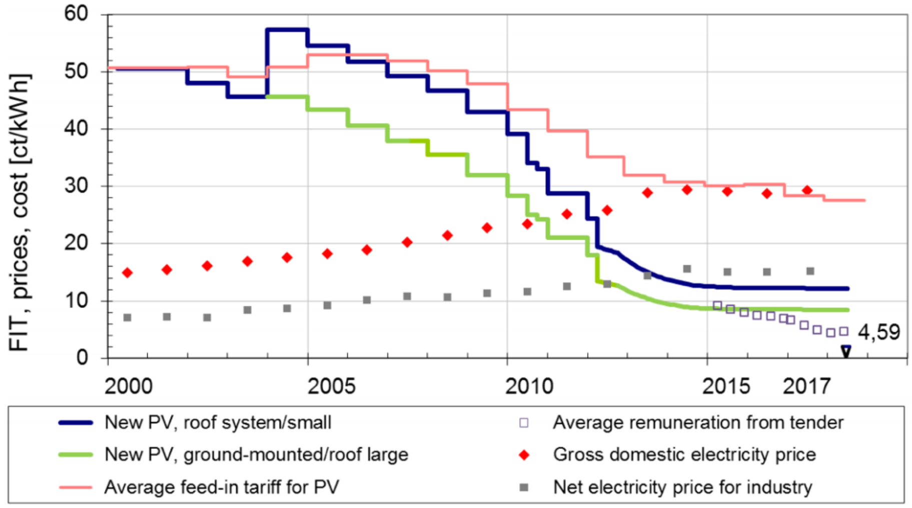


Figure 3.2. Feed-in-tariff for PV power, electricity prices and PV cost installations in Germany, from 2000 to 2017. [5]

Although residential ESS are commercially mature, no battery system leads to profitable consumer investment yet, due to its high prices and not long enough lifespan [6]. The turning point will happen when the increase in self-consumption overcomes the price of a battery storage system. Figure 3.3 shows when the investment could make sense for households regarding the difference in revenues and generation cost (LCOE) of a residential PV system, in €/kWh. The upper blue arrow represents the net present value of revenues during the lifetime of a PV system with storage backup up to 70% of self-consumption in France. The lower blue curve represents the declining PV LCOE [7]. Furthermore, recent announcements in the battery business expect that this window of opportunity might appear earlier, due to an increase in self-consumption rates because of technology advancements.

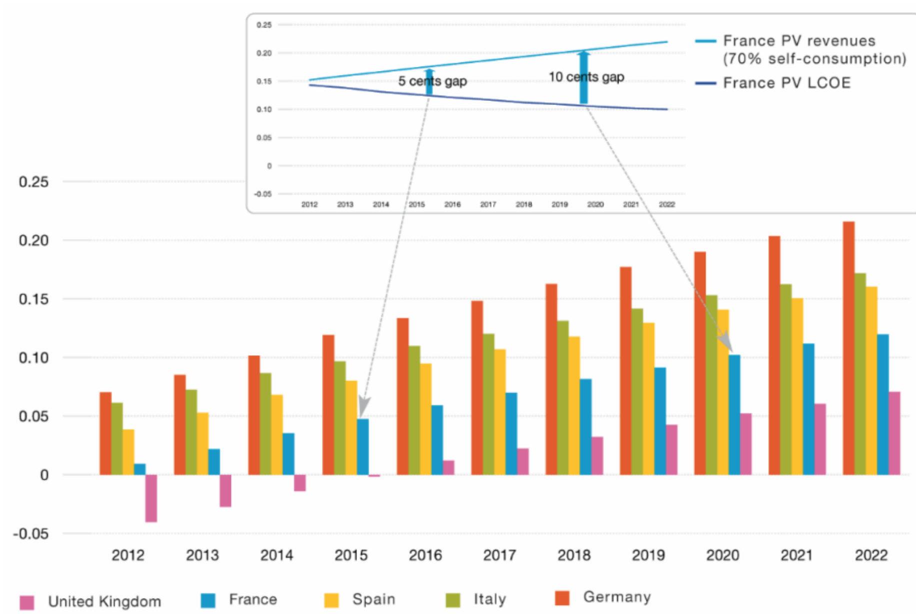


Figure 3.3. Window of opportunity to use storage; difference in revenues and LCOE for residential PV system (€/kWh). [7]

All in all, there are many evidences that there is a market trying to satisfy the needs of an increasingly group of people. Those markets are wider in regions where policies empower self-consumption, where yearly solar radiation is high and/or where people use to live in households. The main ones where most of the players are based and with wider number of customers are EEUU, Australia and Germany. Figure 3.4 shows how the mentioned trend is growing through the pass of the years.

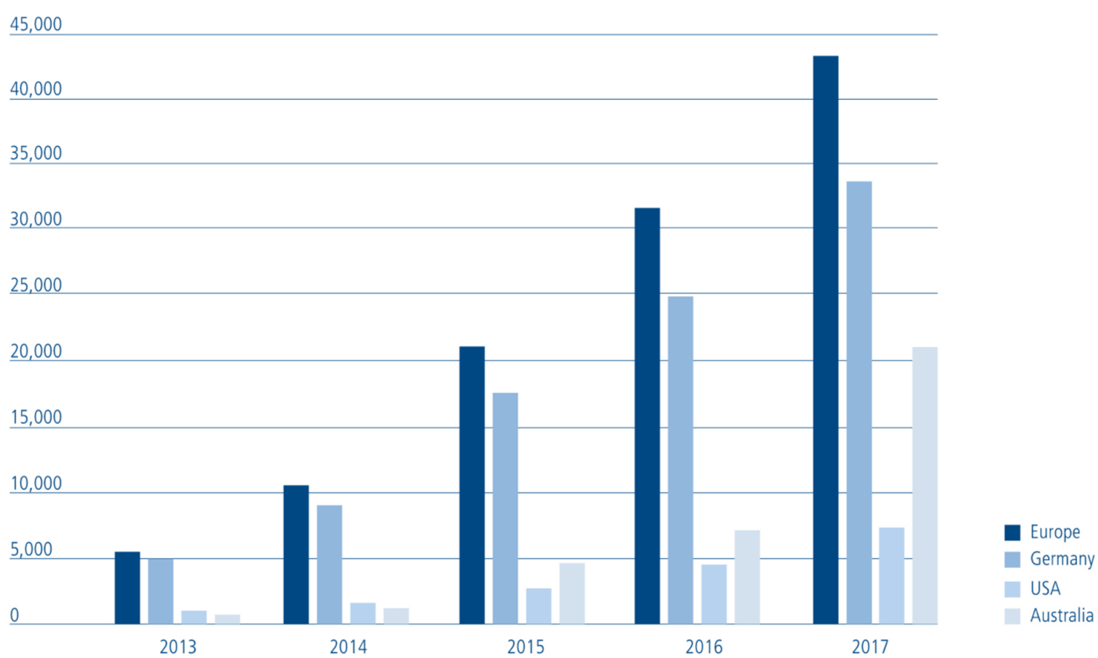


Figure 3.4. Annually installed residential PV storage systems - EU (total), Germany, USA, Australia. [8]

Regarding to an article of PV magazine, 74% of households with PV panels in USA shows interest in storage systems. USA market hit a new high in the first quarter of 2018 thanks to favourable policies, increasing by 26% the total installed capacity in residential storage of the country, with a total of 35.8 MWh, which accounts for 90% of the total capacity installed in the whole 2017. The market is expected to grow 17 times its value from now to 2023, with an annual value of $4300 million [9].

In regards to the Australian market, in 2017 the number of installations of residential storage, with a total of 135 MWh, tripled the amount of 2016. As well as in the US, ¾ of the population expects residential batteries to be usual in households in order to reduce power bills. Actually, 12% of the approximately 172000 new residential PV arrays included battery backup [10].

As shown in Figure 3.4, in Europe Germany possesses 80% of the share of the market. Germany is nowadays leading the global market with approximately 35000 installations in the last year, moving faster than any other country. It is followed by Italy and UK and France by far, and the trend is expected to increase linearly, as Figure 3.5 shows.

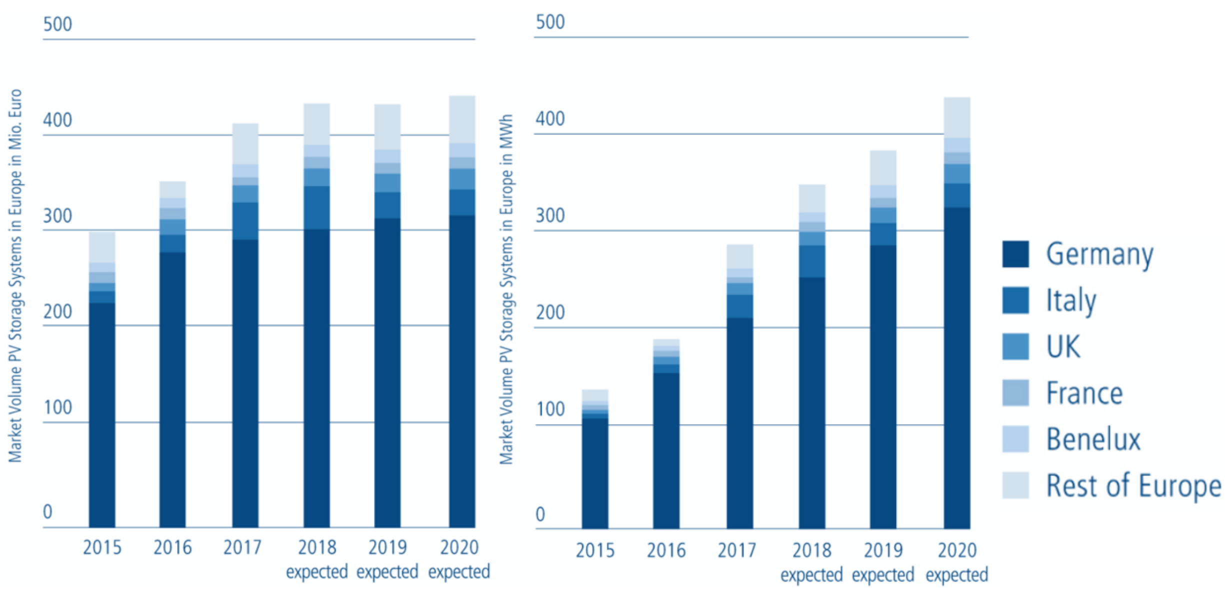


Figure 3.5. Market volume RESS in Europe in MWh and million € (for private use, up to 15kWh net capacity). [11]

As it can be inferred, the expected trend in capacity installed will continue growing during the next years, meanwhile the market volume in € will maintain stable, as prices of RESS and going down. All in all, this market is in a growth stage, and already an increasingly number of players are competing to reach a share in the residential energy storage sector. Hereafter, the main companies will be introduced and analysed regarding to what do they offer to customers, emphasizing in current weaknesses and strengths.

3.2. Competitors analysis

In further sections of the dissertation (Business model), it will be discussed that the beachhead to enter the market for Azolis will be Germany, exactly the Southern region. For this reason, Figure 3.6 illustrates the market share in 2017 of the residential energy storage sector in Germany by companies.

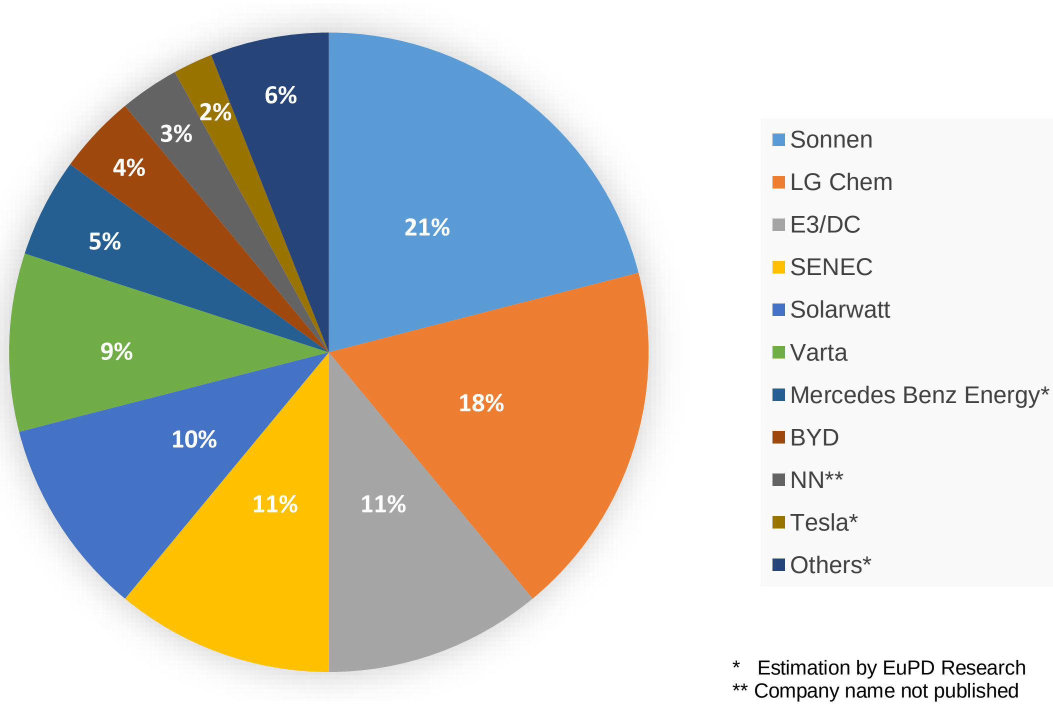


Figure 3.6. Market share of home energy storage systems in 2017, Germany. [12]

As it can be observed, even though Sonnen and LG Chem lead the market with 21% and 18% of share respectively, there is no a predominant company showing a huge difference in market share over the others. Furthermore, many of them share a similar market percentage, showing the current high competition in the sector. The reason behind is that every company offers different features, characteristics, configurations and warranties that may suit differently to each customer. As stated before, there is not configuration of energy storage system yet better than other or that provides the customer a payback on the investment.

Down below, an analysis on each of those companies will be performed. **Some information about prices and datasheet not referenced have been forwarded in mail conversations with distributors, installers and/or manufacturers during the stage in Azolis.*

3.2.1. Sonnen

Sonnen is a German company which builds their battery systems in Germany using Japanese batteries, from Sony, and inverters from Spain (Ingeteam) and/or Bulgaria (Steka Electronic). They offer a modular system, ranging from 5 kWh to 15 kWh in steps of 2.5 kWh, capable to adapt to the needs of the customer. Besides, their systems can be attached in parallel, making it up to 45kWh for more demanding applications. The maximum power that the battery can provide is 3.3 kW. Furthermore, Sonnen offers to the client the possibility of choosing between an all-in-one hybrid system or one AC coupled, depending if their installation is new or it already exists. They have both configurations in high voltage or low voltage. High ones should provide higher conversion efficiencies due to a reduction in losses, but are also more expensive because of protection devices.

Figure 3.7. Sonnen Battery eco. [14]

The chemistry they use is LFP, which provides a battery with longer lifespan, but this technology also involves huge sizes and weight. Even though the design is beautiful and smooth, big capacities of the Sonnen battery can make it look like a refrigerator and weight from 100 kg for the smallest system up to more than 200 kg for the bigger one. Furthermore, this battery cannot be installed outdoors, only indoors. Another important drawback of this system is that does not have backup mode, so in case of outage in the grid, the battery cannot provide external supply to the household.

The warranty of this battery offers very good conditions. It lasts for the first 10 years or 10,000 cycles with no degradation, whatever comes first. Nonetheless, this can be tricky. To cycle it 10,000 times, it must be charged and discharged 2.7 times a day, which is almost impossible, so normally the option of 10 years will happen first. No degradation with Lithium-ion batteries is possible. One possibility why they state that, could be because Sony manufactures LFP batteries of 1.2 kWh [13], so the total capacity of a Sonnen battery module could be 2.4 kWh, and they would degrade by 17% until the warranty is over, which is also quite impressive. For more information about the specifications, please visit [14].

One other possible drawback regarding to competitiveness is the high price of their system. Taking as a reference a system of 10 kWh for comparing it with other companies, the price is about 14,300€, making it 1430 €/kWh [15].

3.2.2. LG Chem

LG Chem is a company only focused in the development of batteries. In their portfolio, they offer low voltage batteries of 3.3, 6.5 and 9.8 kWh, and high voltage batteries of 7 and 10 kWh. Both types can be coupled AC and DC. Nonetheless, they do not offer modularity, since these systems are not expandable; if the customer wants to update the capacity of the system to adjust it better to its needs, the whole battery must be replaced for another one bigger/smaller. Up to two batteries can be connected in parallel, building a system that can reach up to 19.6 kWh. It can be installed indoors or outdoors.

Figure 3.8. LG Chem RESU 10H [16]

LG Chem uses NMC technology, whose higher energy density allowed them to manufacture a very compact battery, reaching almost half size and weight than Sonnen for the same capacities. They also have a good rate of peak power, reaching 3.3 kW for the smallest system and 7 kW for the bigger ones.

The main drawback of this company regarding the point of view of the customer, is that, as stated before, they are only focused on the development of the battery. Therefore, the client must look outside LG Chem to find a compatible battery inverter or hybrid one to complete the system and connect the batteries to the house. Depending on the inverter selected, the good power ratio of these batteries may be limited to the maximum charge/discharge current of the inverter. Consequently, to the apparently low price of these batteries compared to Sonnen, the client must add the inverter costs and separate installation costs for both components of the installation.

Regarding the warranty, they offer a performance of 60% of the original capacity for the batteries after 10 years or 2500 kWh stored for every kWh of capacity of the battery. In case of cycling the batteries once per day, this last part is translated in a warranty of about 8 years and 9 months offering a minimum capacity of 60%. This warranty is slightly worse than the one provided by Sonnen, mainly because NMC technology has shorter lifespan than LFP.

Finally, the price of LG Chem battery of 9.8 kWh is about 530€/kWh, to which the price of an hybrid (or battery) inverter must be added to complete the system [15]. For more specifications data, the following reference provides a link to the webpage of LG Chem where the warranty and datasheet documents can be displayed [16].

3.2.3. E3/DC

E3/DC is a German enterprise that came out from the automotive sector and started as inverter manufacturer and energy management technology company in 2010. Currently, they are a top company in residential and small applications in energy storage using batteries from Panasonic, with many rewards in customer satisfaction and storage PV brand.

Figure 3.9. E3/DC S10 E [17]

They offer all-in-one modular products in a range of low voltage (sing le-phase) and high voltage (three-phase). Low voltage systems offer capacities of 4.6 kWh, 6.5 kWh and 9.2 kWh, meanwhile high voltage are 5, 6.5, 10, 13 and 15 kWh. Nonetheless, the modularity they offer is somehow limited because the customer can only choose to double (or lower by half) the capacity of his/her actual system, making big jumps in terms of capacity. Panasonic uses NMC technology, and E3/DC managed to create an all-in-one system compact, light (around 100 kg) and with a good design that the customer can mount on the wall.

The warranty they offer covers ten years for the whole system, without limits on the cycling of the batteries, always that the unit is installed by a certified installer. They actually rely on their remote maintenance technology to ensure a good performance of the batteries. This warranty is one of the best in the actual market, but it also involves some risks.

Finally, all these high performances have their impacts in price, which is quite elevated, being around 1500€/kWh for the 10kWh [15]. More information is available in the link provided in the reference [17].

3.2.4. Senec

Senec is an Australian company which designs, manufactures and assemblies its system in Germany for the European market. As E3/DC, they use Panasonic NMC batteries, offering a modular all-in-one system, and they coincidentally share the same size of the market. However, Senec offers pure modularity, ranging from 2.5 kWh to 10 kWh in steps of 2.5 kWh. If the customer wants to amplify/reduce its system, he can do it by simply add/remove one of the modules inside of the box.

The maximum power the inverter offers is 2.5 kW, which can be considered low compared to other storage systems. In case of grid outage, if many appliances are connected, the system may shut down. Ready for indoor installation, the design of the system is quite compact, weighting from 77 kg to 152 kg and fitting inside a box one meter tall, but it not as appealing for the human eye as other storage systems shown before, as it can be observed in the figure on the right.

Figure 3.10. Senec Home. [18]

The warranty they offer covers 10 years or 12,000 cycles, whatever comes first. Again, making use of marketing tricks, the most probably case scenario is that those 10 years come first, since cycling the battery once per day would take around 33 years to cover all those cycles. An average customer will usually cycle the battery even less than once per day, being this number close to 0.8-0.9 times. The cost per kWh for their model of 10 kWh is about 1200 €/kWh [15]. For more information about specifications, please visit the following provided in reference [18].

3.2.5. SolarWatt

SolarWatt is a German company, not only specialised in RESS, but also in manufacturing photovoltaic systems. This company may be the only one in Germany who can provide to the customer looking for new installation PV panels plus storage system.

However, they have a little drawback, and it is that their storage system is DC coupled and not all-in-one-system, which means that the customer will need a solar inverter to complete the installation. The system is connected directly to the PV panels in DC, and afterwards a compatible solar inverter is needed for converting this DC energy into AC.

Figure 3.11. SolarWatt MyReserve Matrix. [38]

Because of this configuration, they can boast of having very good overall efficiency in their system, because they do not take into account the last step of converting the DC energy into AC through the inverter, because it does not belong to their system. They use NMC cells, and as it can be inferred in Figure 3.11, the system is quite compact and can be installed only indoors. Between all systems analysed, this is the first one that offers all the components outside of a box, which reduces weight and optimises space.

SolarWatt storage system consists of one charger/discharger for batteries called MyCommand (in black in Figure 3.11), and batteries of 2,4 kWh that can be coupled together in parallel. The system is expandable up to 5 batteries connected together, summing a total capacity of 12 kWh. One other drawback is that each battery is only available to provide 0,8 kW of power. For example, in case of having a system of 2 batteries (4,8 kWh), only 1,6 kW of peak power could be delivered, which may be insufficient in case of outage of the grid to run a determined number of household applications. On the other hand, the 4kW delivered by the biggest system of 5 batteries, can be limited by the solar inverter that connects the system to the power house.

The warranty they offer covers 10 years for the batteries with a minimum capacity of 80% and 5 years for MyCommand (the charger/discharger). Using NMC batteries, this warranty can be impressive, as it almost does not consider deterioration. The price for their system of 9,6 kWh is about 1125 €/kWh [15], to which the price of a solar inverter must be added. For more information about specifications, please visit the link provided in the following reference [19].

3.2.6. Varta

Varta Storage, based in Bavaria, Germany, is a company specialized in Lithium-ion battery storage for mobility, residential and commercial applications. With 130 years of expertise, they offer an all-in-one high voltage system with 4 battery modularities ranging from 3.3 to 13 kWh in steps of 3.25 kWh.

They use NMC cells with 90% depth of discharge, which is on the average, and as other NMC batteries, they space is compacted inside their box. Nonetheless, it is quite heavy, from 95 kg for the smallest configuration to 165 kg for the biggest one. Another drawback is their temperature range. Even though it is intended for indoor installation, where temperatures are more regular than in the outside, their range goes from 5ºC to 30ºC (normal ones goes from 0ºC to 45ºC). The upper limit can be easily surpassed during summer, where the system is supposed to work at higher demanding pressures. This could be a problem for the customer.

Figure 3.12. Varta Element. [20]

The warranty covers 7 years of maintenance and 10 years after purchasing batteries with an expected residual capacity of 80%. Again, with a range of temperature that short, this can cause some problems to Varta when applying their warranty. The cost of their system of 9.8 kWh have a cost of 1150€/kWh. For more information about the specifications, please visit the link provided in reference [20].

3.2.7. Mercedes-Benz Energy

Mercedes-Benz Energy started their business into residential storage systems at the end of 2016. Nonetheless, they failed in the attempt on competing against Tesla, their main competitor, and exit the market in April 2018, even though they achieved 5% of the market share in Germany. The scale and resources were not enough to sustain its residential storage business. Instead, they switched to industrial and big scale storage systems. Mercedes is aiming to come back in the residential sector with second-life EV batteries in the future, whenever batteries deteriorates in electric vehicles, in order to extend the lifespan of the product and reduce manufacturing costs [21].

3.2.8. Tesla

Even though Elon Musk's company only have 2% of the share of the market in Germany, it is worth it to comment and analyse their system, since for marketing force it has become one of the most famous RESS in USA, Australia and somehow worldwide.

Thanks to the gigafactory, Tesla achieved to lower the prices of Lithium-ion NMC batteries until levels that seemed impossible for these days. This is the main competitive advantage of Tesla, achieving a RESS which is around 400€/kWh. However, it is not an all-in-one system; a compatible solar inverter is required between the PV array and the storage system because it is AC coupled. This can add some cost to the system in case of installing new installation, but anyway, it is still very far from their competitors.

Figure 3.13. Tesla Powerwall. [22]

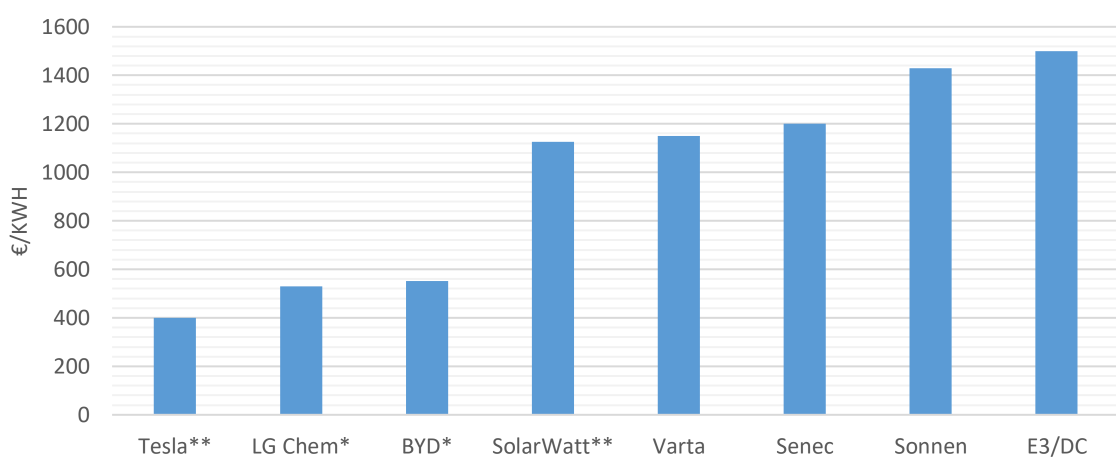
The main drawback that the Tesla Powerwall II presents is 0 modularity. It consists on a system of 13,5 kWh, that the customer must take or leave it. In the majority of cases, this capacity may be oversized for households in Europe. Thus, it lacks of adaptability to the customer needs and probably the system would never operate optimized. Nonetheless, the low price can make it worth it. Furthermore, it offers a high power delivery, up to 7 kW peak and 5 kW of continuous power. Again, it is weird that a household in Europe may need all that power at once, but the system can deliver it. The design, for having that capacity, is very compact and light, weighting only 125 kg and it can be installed both indoors and outdoors. It has a high round-trip efficiency of maximum 90%, because it does not take into account the efficiency of the solar inverter missing. For more information about specifications, reference [22] provides a link to Tesla webpage.

All in all, Tesla, who launched the Powerwall II in October of 2016, has been overtaken by many competitors in the market by simply adjusting other batteries to the customer needs. The next version of the Powerwall, however, could offer various modularities and be an all-in-one system, and with the very low prices of the batteries that the company can achieve, they could performance an impressive come back in the market share.

Hereafter, a summary the pros and cons of every of the competitors in the German market is presented, regarding the main worries of the customer. On the column "Performance", many aspects detailed in the previous section analysing the competitors are taken into account, such as power delivery, back-up function, all-in-one system (because all the components will work more optimized in an all-in-one system, since there is a preliminary design on the assembly of them), etc, etc.

	Chemistry	Modularity	All in one	Performance	Warranty conditions	Compact design
Sonnen	LFP	★★★★⯪	Yes	★★★★☆	★★★★⯪	★★☆☆☆
LG Chem	NMC	★★☆☆☆	No	★★★☆☆	★★⯪☆☆	★★★☆☆
E3/DC	NMC	★★★☆☆	Yes	★★★★★	★★★★★	★★★★★
Senec	NMC	★★★★⯪	Yes	★★★⯪☆	★★★☆☆	★★★⯪☆
SolarWatt	NMC	★★★★★	No	★★★☆☆	★★★★☆	★★★★★
Varta	NMC	★★★★⯪	Yes	★★★☆☆	★★★★☆	★★★☆☆
Tesla	NMC	★☆☆☆☆	No	★★★★☆	★★★★☆	★★★★★
BYD	LFP	★★★★⯪	No	★★★⯪☆	★★★★☆	★★⯪☆☆

Table 3.1. Summary of features offered by the competence.



* Only the battery is offered. Hybrid inverter or solar+battery inverter must be added to the cost.
** Solar inverter is required to complete the installation. Added cost must be taken into account.

Figure 3.14. Price comparison in €/kWh of the main actors in Germany.

4. Product Development and Design

After introducing the state-of-the-art of residential energy storage systems and analysing what the main competitors offer in the market that Azolis is intended to enter, the discovers on the opportunities for developing a competitive system in terms of technology, performance, adaptability to the customer, design, price and other factors will be explained down below. The idea generation or concept development of the product object of study in this dissertation came by analysing how to overcome the competence, by designing a good and well balanced product on its global. After the main ideas are deployed, the design and decision making of every of the components of the residential energy storage system will be explained, with the presentation of the final product.

Before, a brief introduction of Azolis will be done to better understand the nature of the project. Azolis is a small enterprise with headquarters in Paris (France), Casablanca (Morocco) and Amman (Jordan) whose main activity is the distribution and installation of solar PV panels and HSW systems around Africa and Middle East Asia, for mainly industrial applications. Mr. Guillaume Jeangros, the CEO of the company, wanted to study the feasibility of developing storage system solutions, and he focused in the residential market as a first approach, opening an affiliate start-up with headquarters in Morocco. It was there when this project started, having the author of the dissertation, Rafael Lopez Pizarro, working as a Project Manager developing a competitive residential solar battery system. Hereafter, the main findings and ideas after analysing the market will be deployed.

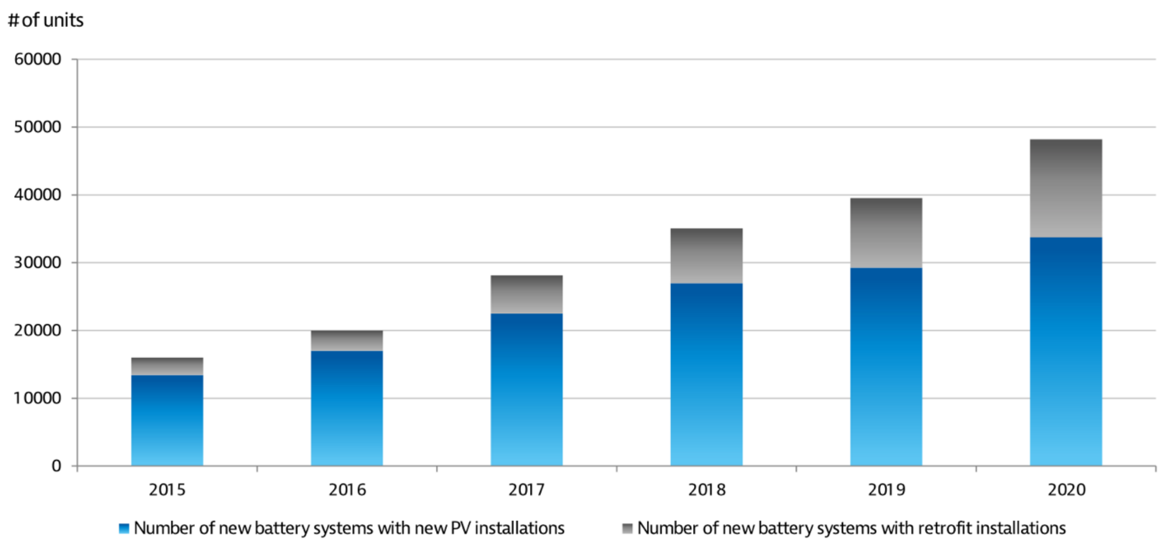
4.1. Design Thinking and Strategy Definition

In this section, the main features that the RESS (Residential Energy Storage System) object of development will offer are listed. This consists on how the idea was generated, and in further steps the development of this idea will be explained with the sizing and choice of every component. Here are the main points that are believed that are important for the customer, no matter the order:

- Modular adaptability
- All-in-one hybrid system
- Overall good performance
- Long lifespan
- Compact design
- Warranty conditions
- Competitive price

Each customer has different needs regarding their household consumption profile and PV array size. Therefore, one of the main features that the battery system must have is the adaptability to cover the needs of each client. This adaptability or suitability can be achieved by offering **modularity**, so to say, different battery modules attached/attachable together to reach the optimized capacity size for the household.

Addressing another point, many companies like LG Chem or BYD, offer just the battery, and is the client who has to look out of the enterprise for a battery/hybrid inverter to complete the installation. Others, like SolarWatt, provide a DC coupled battery with a solar inverter integrated, but the customer may look for a battery inverter that adds cost to the installation. The decision of how many components of the installation are going to be offered to the client, will determine which customer segment is the company directly targeting, whether to people with already existing PV installation, or to both existing and new installations. Figure 4.1 shows the estimated number of new RESS installed per year, differentiating in between already existing PV installations and new ones.



Note: assumptions: new annual PV installations 2015-2020: 1.4 GWp. Source: year 2015: Federal Network Agency, KfW Speichermonitoring 2016; year 2016: preliminary projection by ISEA RWTH Aachen; years 2017-2020: own calculation and estimate, 2017

Figure 4.1. Estimated number of newly installed residential PV-battery systems in Germany. [23]

As it can be inferred, the number of people installing battery systems with new PV installations doubles more than the quantity of people with existing PV array that is willing to add batteries. To target all of them at the same level, the best option is to come up with an **all-in-one system**, including a **hybrid** inverter that works at the same time as battery inverter and solar inverter. This way, the enterprise offers the client all the package, and they do not have the need to look outside for another component to match with the batteries and PV panels. Hybrid inverters do not belong to an old technology, on the contrary, it is quite a new product and just few companies manufacture them. As far as technology moves forward, prices are decreasing faster and faster, being nowadays even or slightly cheaper than buying a solar and a battery inverter.

Another problem the customer may find when installing a battery system is the size and the weight of the whole equipment, especially when it must be installed only indoors. The best way to overcome this point is to choose a battery chemistry with high specific energy. The two main chemistries widely used in residential storage are **NMC** (Nickel, Manganese, Cobalt) and **LFP** (Lithium Iron Phosphate). As it will be discussed in section 4.2.1, NMC doubles LFP in terms of specific energy, but LFP offers higher lifespan. Nonetheless, taking a look to the trend of the market, many are the companies who switched from LFP to the NMC technology. As shown in Figure 4.2, NMC will be closed to double the demand of LFP by 2025. Besides, the gigafactories announced by Tesla and other companies such as SK Innovation (in Hungary) [24], will drive the price down thanks to process manufacturing improvement. Therefore, NMC technology looks more promising than LFP because of high energy density and lower price trends.

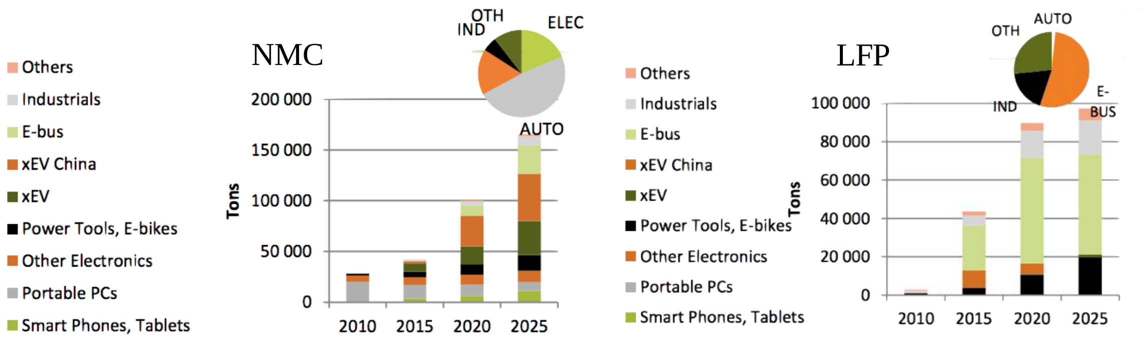


Figure 4.2. NMC vs LFP in market demand. [25]

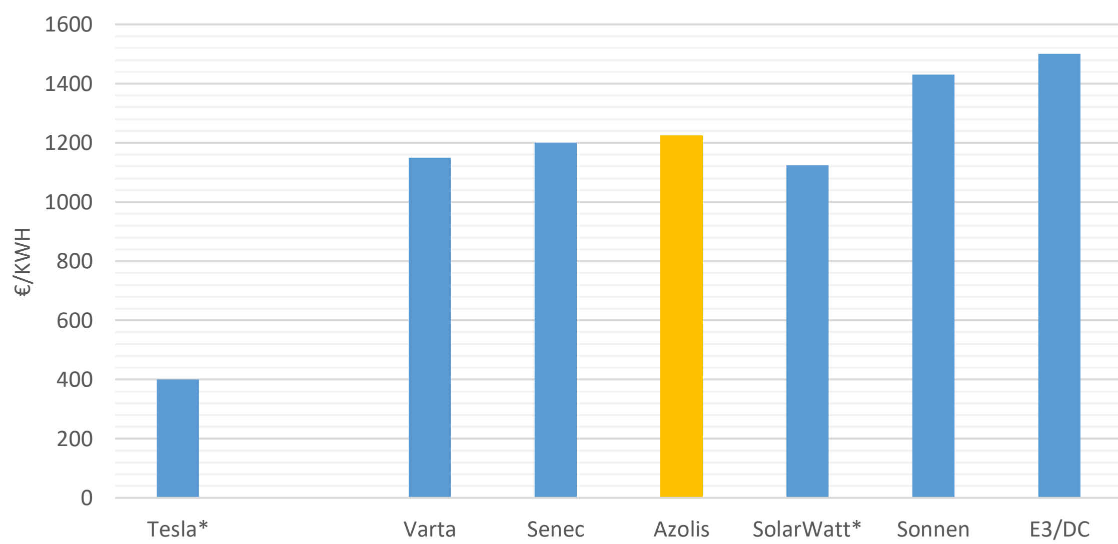
Up to now, battery technology and inverter choices have been made. Those are components that belong to a mature market that is moving forward with technology advancements inherent to big companies. From the start-up point of view, it is believed that the improvement field to try to overcome our competitors could be more easily related to the management of the battery system and the energy flows. For this reason, more effort will be done in trying to invest in an innovative Battery Management System and Energy Management System, rather than looking for the best batteries and inverters. Therefore, the system can perform in a more efficient and optimised way, maximizing the return on the investment. By following this strategy, the lifespan of the batteries could be extended, and maybe create for the first time a RESS that leads to a payback on the customer's investment. Furthermore, this strategy could provide the possibility to offer better warranty conditions than many competitors, and gain the trust of clients.

In order to achieve a better competitive price, the system will be assembled strategically in Morocco to lower manufacturing costs. Moreover, it will be intended to be ready for indoor installation, so less IP rate of protection will be demanded, and thus, cheaper will be the installation.

All in all, regarding Table 3.1, where Azolis is aiming to be satisfying customer needs is shown in Table 4.1. Regarding prices, in Azolis the target is to compete against direct competitors. Those competitors are Sonnen, E3/DC, Senec, Varta, Tesla and SolarWatt, because they offer systems with all-in-one configuration or inverters integrated. As it can be inferred from Figure 4.3, the objective is to be as close as possible to those relatively low price all-in-one systems, offering lower price that the companies listed on the right of Azolis.

	Chemistry	Modularity	All in one	Compact design	Warranty conditions	Performance
AZOLIS	NMC	★★★★★	Yes	★★★★★	★★★★★	★★★★★
Sonnen	LFP	★★★★⯪	Yes	★★☆☆☆	★★★★⯪	★★★★☆
LG Chem	NMC	★★☆☆☆	No	★★★☆☆	★★⯪☆☆	★★★☆☆
E3/DC	NMC	★★★☆☆	Yes	★★★★★	★★★★★	★★★★★
Senec	NMC	★★★★⯪	Yes	★★★⯪☆	★★★☆☆	★★★⯪☆
SolarWatt	NMC	★★★★★	No	★★★★★	★★★★☆	★★★⯪☆
Varta	NMC	★★★★⯪	Yes	★★★☆☆	★★★★☆	★★★☆☆
Tesla	NMC	★☆☆☆☆	No	★★★★★	★★★★☆	★★★★☆
BYD	LFP	★★★★⯪	No	★★⯪☆☆	★★★★☆	★★★⯪☆

Table 4.1. Market comparison of features that Azolis is intending to achieve.



* Solar inverter is required to complete the installation. Added cost must be taken into account.

Figure 4.3. Azolis target price compared to direct competitors.

Finally, a summary of the design thinking and strategy definition are summarized hereafter:

- The system must offer a wide range of modularities to adapt it to the needs of each client, with all the components of the installation (all-in-one), so it can be optimized and offer a good rate of overall performance.
- Major investment efforts will be released in the managing of the system (BMS and EMS), so better performance and lifespan will be provided.
- Competitive price will be achieved by conducting the assembly of the components of the system in Morocco, and also by choosing simple sophistication on some parameters which have not major relevance, as indoor installation instead of outdoor, or low voltage system instead of being a high one.

Hereunder the development of each of the system components will be defined. It must be noticed that, even though the elements of the whole system are separated in the dissertation, the definition and sourcing of all of them took place simultaneously and in parallel.

4.2. Battery development and design

4.2.1. Preliminary definition of parameters

The battery is the main element of the system. Its parameters must be properly defined to ensure a good performance. The first feature to determine is the capacity of the battery. For this purpose, a preliminary study taking into account the solar capacity factor, rates of self-consumption and average PV array power per household in some countries in Europe have been performed. Table 4.2 shows the average solar capacity factor, extracted from a study from Energy Matters [26], and the self-consumption rates potential from Figure 3.1.

Country	Capacity factor (%)	Hours per year	Self-consumption rate (%)
Germany	12.2	1069	40.5
Italy	14.5	1270	32.0
UK	10.1	885	40.5
France	12.3	1078	38.0
Benelux	10.5	920	42.0

Table 4.2. Capacity factor and self-consumption rates of top countries in the RESS market.

The self-consumption rate determines how much energy coming from the PV panels, in average, is going to be consumed by the household. Therefore, the rest of energy, which normally is lost, can be supposed to be for storage purposes. Iterating with different PV sizes and calculating the daily hours in average that the PV array may be working through the capacity factor, the estimated energy to be stored regarding these countries is calculated. Taking into account that an average PV panel has a power of 275 Wp, the approximate number of PV panels needed is also determined, to give an idea of how big should that installation be in order to store that energy. Results are shown in Table 4.3.

	Germany	Italy	UK	France	Benelux
2 kW PV (7 panels)	3.48	4.73	2.88	3.66	2.92
3 kW PV (11 panels)	5.23	7.10	4.33	5.49	4.38
4 kW PV (15 panels)	6.97	9.47	5.77	7.32	5.85
5 kW PV (18 panels)	8.71	11.83	7.21	9.15	7.31
6 kW PV (22 panels)	10.45	14.20	8.65	10.98	8.77

Table 4.3. Estimated average energy to be stored regarding the PV size per country.

It is unlikely to have a system bigger than 22 panels of 275 Wp in a household. In other words, the percentage of customers with such a big installation may be that low that it is not worth it to focus on them. Also, because bigger PV installations could probably not be suitable to connect to the RESS due to the input value of the inverter. Hence, taking into account that Germany accounts for approximately 80% of the European market, designing a RESS to store an approximate maximum around 10 kWh of energy per day, can be enough to satisfy the main volume of the market. Regarding the modularities, everything containing 3 to 5 modules of battery may be enough. At the end, it will depend on which options regarding quality and price are found in the market.

Regarding the voltage of the battery, there are mainly two options: **low-voltage**/high-capacity battery of 48V, or **high-voltage**/low-capacity systems of 400V. Shortly explain, low voltage batteries offer better battery prices, meanwhile high voltage batteries offer slightly higher efficiencies due to the use of lower currents. However, the key point in this issue remains on taking a look to the market trend. The most relevant sector that drops the cost down of electrical batteries (especially Lithium-ion) and make them competitive in terms of €/kWh is the automotive. This sector leads to the use of cells of low voltage and high capacity. For this reason, and considering that from a start-up point of view it is better to bet for reduction of costs, the low voltage system of 48 V has been chosen. Also, because high voltage systems would limit the modularity of the system for small PV array sizes.

In previous section, the discussion about the chemistry choice between NMC and LFP was focused in the market trend, which makes NMC more promising in terms of low prices. Hereafter, the discussion is more focused in technical parameters, reaffirming also the trend in price.

Taking a look on the characteristics shown in Figure 2.2, NMC doubles the specific energy of LFP, which means that, apparently, the system can offer the same energy storage capacity occupying half of the space of LFP chemistry. The secret of NMC batteries reminds in the combination of Nickel and Manganese. Nickel is known for high specific energy but poor stability; Manganese is known for low specific energy but it forms a spinel structure that achieves low internal resistance and high stability. Combining these metals enhances each other strengths.

In terms of specific power, the actual application does not demand a lot of power release, so both technologies are acceptable in the same level. Both chemistries are performing at a similar level and the cost is also similar. This can be surprising taking into account that NMC technology came up to a commercial level recently, around 2015, being the price double than LFP. The truth is that, as it was discussed in section 3.2, top companies like Tesla, LG Chem, Samsung SDI, Panasonic, and most of all the automotive sector, are pushing towards NMC technology instead of LFP, reducing its costs at a faster level. Actually, in Figure 4.4 it can be observed an estimated trend on how the prices on NMC batteries are expected to decrease. One of the reasons are the new generations of NMC, which are reducing the percentage of cobalt in the cathode. Nowadays the most extended are NMC 622 (60% Nickel, 20% Manganese and 20% Cobalt), but new ones composed by 80%, 10% and 10% respectively, are emerging to a commercial stage, with higher energy density.

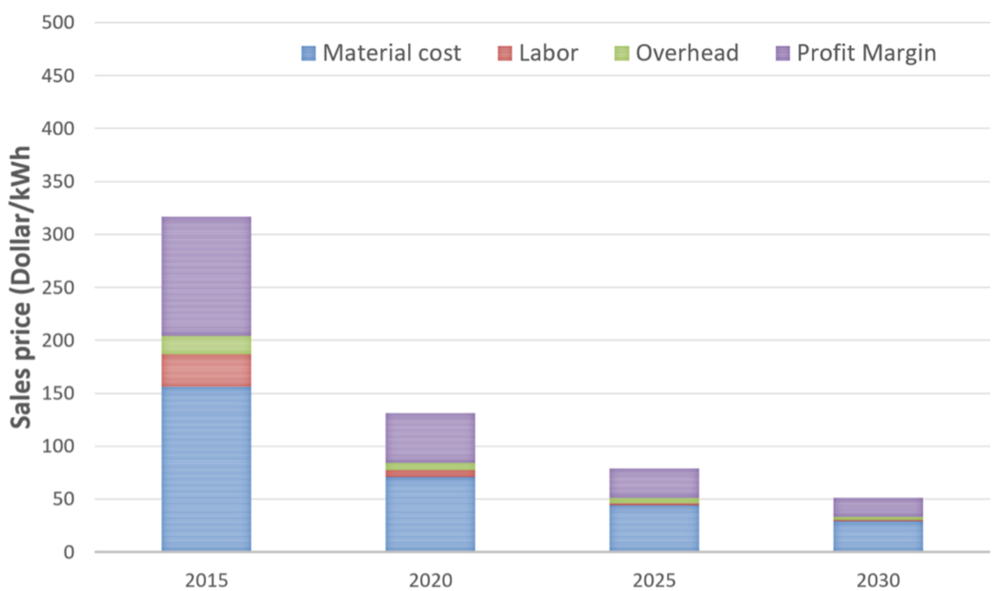


Figure 4.4. Prediction of sales price of NMC batteries up to 2030. [27]

The last feature, but not least, to compare in between both technologies is the safety. As stated, NMC technology is quite new and it has not the maturity of LFP technology, which has been tested since the beginning of the century. For this reason, Battery University [1] and others professionals catalogue NMC as slightly less safe than LFP. Nonetheless, consulting with many manufacturers, NMC is providing same levels of safety than LFP technology. Actually, new generations of NMC are showing more and more stability for mobility and stationary applications. Therefore, **NMC** looks the more suitable technology to develop a battery system, mainly because of its high energy density and expected cost reduction.

The rest of parameters of the battery, such as charging/discharging currents (which will determine the power), expected cycle life and others will depend on what the market can provide. Next table summarises the preliminary parameters that are intended to be set in the battery selected, always depending on what it can be found in the market.

Chemistry	NMC
Voltage	48V (low voltage)
Capacity ranges	50Ah – 70Ah
Energy capacity	2.5kWh – 3.5kWh
Modularities	From 3 to 5

Table 4.4. Preliminary parameters definition for the battery.

4.2.2. Sourcing and partnership establishment

After studying and defining the main battery parameters, the research in the market seeking for a partner who could collaborate in the project started. The first point of reference to look at would be the automotive market. The reasons are because they work mainly with NMC cells, manufacturing low-voltage batteries, and because from the strategic point of view, some companies could be willing to enter to a new market such as residential storage, demanding and promising. Notwithstanding, other manufacturers coming from other sectors will be contacted too.

With the premise that the company is incorporating an innovative and unique BMS in the RESS that can extend the lifespan of the battery longer than any other in the market (this idea will be introduced in the next section), and that we intended to design a modular all-in-one system with assembly in Morocco in order to lower costs, the attention of the most relevant NMC battery manufacturers was tried to attract. Thereupon, a list showing the manufacturers contacted with their respective information is displayed. All of them offer NMC technology with cells that could be suitable for residential storage applications.

Company 1	
Company 2	
Company 3	
Company 4	
Company 5	
Company 6	
Company 7	
Company 8	
Company 9	
Company 10	
Company 11	
Company 12	

Table 4.5. Battery manufacturers contacted and their respective brief introduction.

Being a start-up it is not easy to catch the attention of big manufacturers, even with the statement of the BMS innovation. After some tries, these are some of the replies that Azolis got from the manufacturers listed above with a negative feedback to implement a partnership.

Others like Company 3 or Company 8 directly did not reply. **Company 3** probably dismissed our enquiry also for being a start-up with the corresponding low volume of market. **Company 4** was interested in cooperating in the project, but they advised us that their production line "would not be available until July 2018" for satisfying the enquiry.

Regarding to the others, Azolis got positive feedback from them and the possibility of starting a negotiation to establish a partnership. Nonetheless, **Company 1**, after the next reply displayed and the corresponding NDA signed by Azolis, did not reply again, despite our insistence.

The battery manufacturers willing to cooperate with Azolis provided a list of different cell specifications that could match our requirements, so the enterprise could choose which one could fit better in the project. Those specifications are listed in Table 4.6. Further information, regarding discharge curves and other parameters, is not display because of the big volume it may occupy.

NMC cells usually provide 3.65V of nominal voltage. To arrive to 48V, up to 14 cells must be connected in series, exceeding this potential with some extra volts up to 51.1V, thus, providing more energy. In regards to the results of estimated energy to be stored shown in Table 4.3, designing a system with a capacity not superior to 12 kWh should be enough to target the main volume of the market. Taking into account that it is intended to have modularities from 3 to 5, the best range of cell capacities would be between 40 Ah and 70 Ah, so to say, battery modules from 2 kWh to 3.5 kWh. In order to increase capacity, cells can be connected in parallel. By performing some calculations, the best possible configurations of cell combination are shown in Table 4.7. With all these information, the decision of which partner and afterwards which cell configuration shall be use in the project must be developed.

The highest performance cells are the ones from **Company 9**, which already offers the next generation of NMC cells, with the cathode made out of 80% Nickel, 10% Manganese and 10% Cobalt. It has the highest specific energy so far and maximum peak power release. Furthermore, regarding their specifications, it provides longer life expectancy than any other, by almost doubling the lifespan. On the contrary, the main drawback is that Company 9 does not provide smaller capacity cells, so the modularity, which is one of the main features of the system being designed to better adapt to the customer needs, is limited to only two modules. This restricts a lot the marketing flexibility. Furthermore, this higher performance involves a higher price of around 50€/kWh than its competitors, which can be a relevant disadvantage when competing in the market.

Company 2 and **Company 11** offer very similar performance, with same technology (NMC 622), life expectancy and similar curves of discharge. The main difference relies in the specific energy. 10 kg of battery from Company 2 can deliver 1.65 or 1.9 kWh, depending on the choice, meanwhile Company 11 can deliver 2.2 kWh. Reaffirming that one of the features of the battery is to achieve a compact design, Company 11 could be a better option. Besides, they offer longer maximum pulse discharging current, achieving a power 3 times higher than the nominal capacity during 30 seconds.

Last but not least, **Company 5** offers a customised pack for Azolis of 53Ah, to offer a very good range of modularities. However, the lifecycle their cells offer is far from being similar to the others. At 0.2C of standard charging/discharging current, which stresses the cell to a lesser degree, they assure 1000 cycles with a capacity ratio no lower than 80%. That quantity of cycles is very low, since the cell is probably tested at optimum conditions at 25ºC, and its performance in real conditions may be lower.

All in all, the best cell options are the ones offered by Company 9 and Company 11. Those parameters are confidential and shown in the Annexs.

Table 4.6. Summary of cell specifications from manufacturers.

Table 4.7. Summary of battery specifications.

Going on with the negotiations, Company 11 appeared to be more proactive and give to Azolis facilities to develop a more promising partnership than Company 9. Those facilities were focused on importation terms, battery warranty and certification costs. From the experience, a usual battery manufacturer does not have on stock the specific model a client may order. They need to manufacture it, and for its commercialization, certification is needed, even though the cells in the battery are already certified. Those certifications have a cost associated, which normally the client pay. The mandatory certifications a product of these characteristics must have in order to be commercialized in Europe are the following ones:

- CE marking. Indicates conformity with health, safety and environmental protection standards for products sold within the European Economic Area (EEA).
- UN 38.3. Transportation testing certification for Lithium-ion batteries to ensure the safety of batteries during shipping.

The sales manager of the company communicated that they could bear the cost of CE marking if the company quantity order reaches 150 pieces, which is feasible for a first commercial stage. UN38.3 is already implemented in any product Company 11 is manufacturing. Due to internal policy, the warranty they offer for a battery is 2 years, but for Azolis he attained a warranty of 3 years. About the importation terms, he also provided an offer of switching from EXM to FOB in the incoterm (International Commercial Terms) for the same price, in which the buyer avoids the cost of importation from the manufacturer's location to the port of exportation.

On the contrary, Company 9 was very strict in its conditions from the beginning. Even though the high performance of the cells provided by Company 9, the lack of modularity that the product would have offered and the extra cost of its cells, certification and EXM incoterm, would have added some disadvantages to the proper development of the project.

With all these advantages provided, **Company 11** became the battery provider for the project carried out by Azolis.

4.2.3. Final battery parameters definition

After taken the decision of establishing a partnership with Company 11, the rest of parameters of the battery must be defined.

The first one was to determine which cell is more suitable for the product, decision that will define the modularity, energy and power that the system would deliver. In the first instance, the cell of 45Ah seemed the more suitable one for simplicity and because the product would have offered a good modularity from 2.3 to 11.5 kWh. However, the sales manager of the battery manufacturer strongly suggested to choose the cell of 17.5 Ah with a configuration of 3P14S (3 in parallel and 14 in series). The reason is because this one is the cell they tested for longer, knew better in terms of performance and used widely in many applications for many customers.

By choosing this cell, a configuration of 3P14S had to be executed to achieve the desired capacity of 52.5Ah and nominal voltage of 51.1V. It was worrying how that could affect the sophistication and cost in the BMS. Thus, the issue was forwarded to the BMS manufacturer, and the answer was very clear, the setting of the BMS would not be affected, since the terminals are going to be 14, no matter how many cells are inside connected in parallel.

Therefore, cell 17.5 Ah was selected to manufacture modules of 2.68 kWh, with the possibility to attach 2, 3 or up to 4 of them in parallel to reach modular capacities of 5.36, 8.04 and 10.72 kWh. The discharge curves of this cell at different currents and temperatures, together with the life cycle life curve are displayed in the next page, everything provided by Company 11.

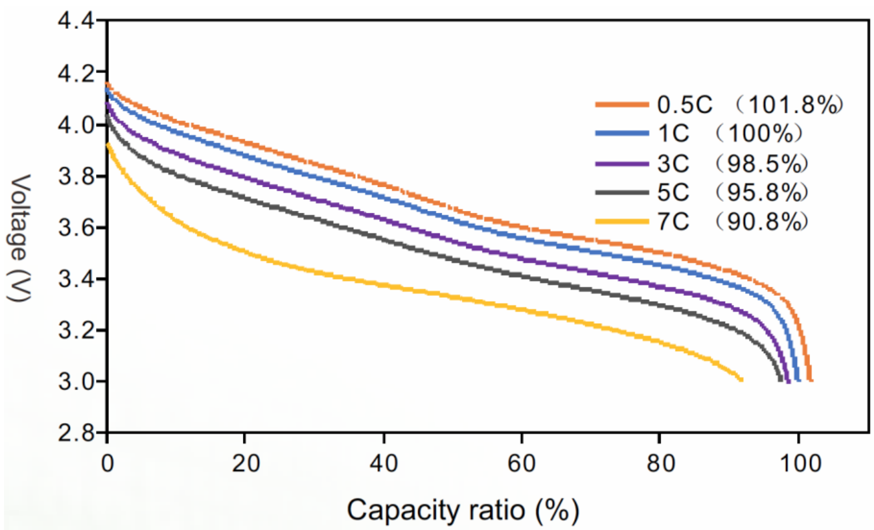


Figure 4.5. Discharge curve at different currents.

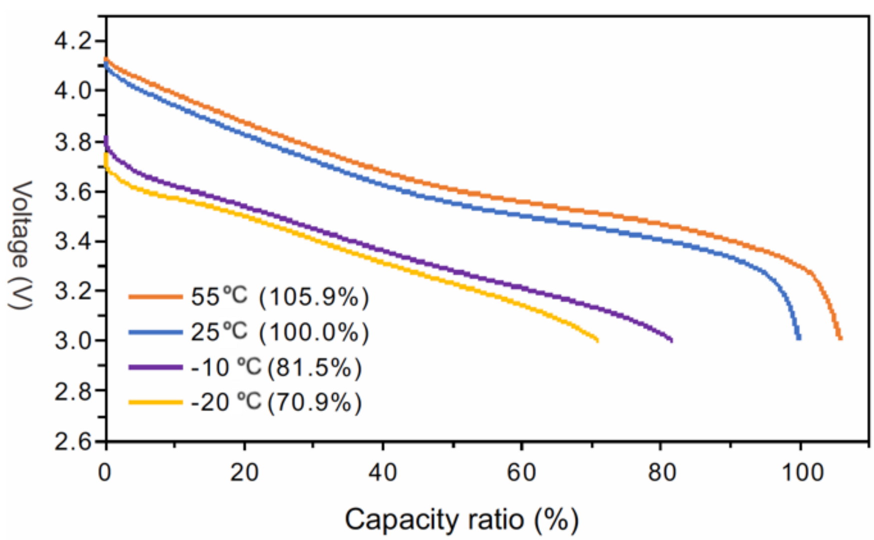


Figure 4.6. Discharge curve at different temperatures.

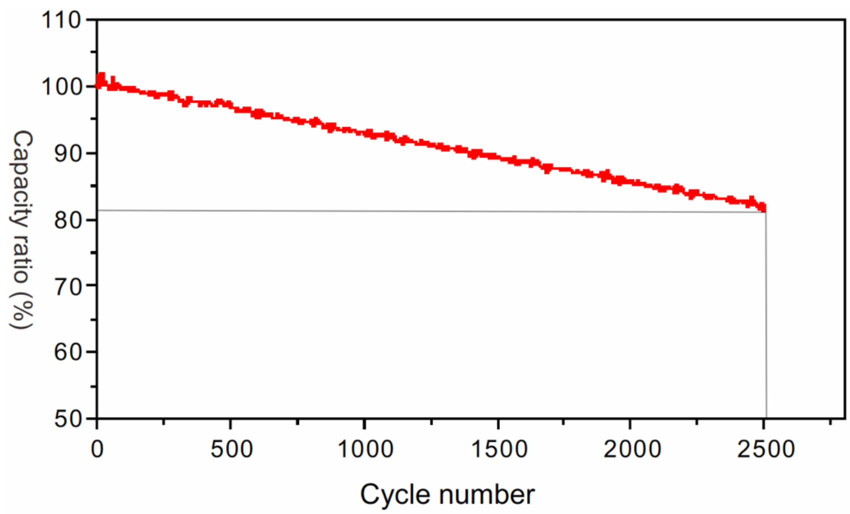


Figure 4.7. Cycle curve of the cell selected. Capacity retention vs. number of cycles.

Temperature	Charge	Discharge
-20°C ~ -10°C	-	1 C
-10°C ~ 0°C	0.1 C	1 C
0°C ~ 5°C	0.2 C	1 C
5°C ~ 10°C	0.4 C	1 C
10°C ~ 15°C	0.7 C	1 C
15°C ~ 45°C	1.0 C	1 C
45°C ~ 55°C	0.5 C	0.5 C

Table 4.8. Charge/Discharge rates recommended regarding different temperature ranges

As it can be inferred from the discharge curve at different current rates (Figure 4.5, the battery has been designed to work at perfect conditions when discharged at 1C, meanwhile 0.5C stresses the battery in a lesser degree. Ratios of 3C or higher will not be achieved because the BMS will limit the discharge current of the battery to minor values.

Since the installation will be designed for indoor installation, the operating temperature range at which the battery will be operated will be softened and closer to 25ºC, so none of the conditions expressed in the discharge curves at different temperatures (Figure 4.6) are likely to happen. Furthermore, Table 4.8 adjusts the different current rates at which the battery is recommended to performance regarding different temperature ranges.

The test conditions for the cycle curve (Figure 4.7) are at 25±3 ºC, charging at 1C to 4.2V and discharging at 1C to 3.0V. This means cycling the battery at 100% DOD, which stresses it and shorten its lifespan.

However, if 80% DOD is selected, the usable capacity of the battery decreases from 2.68 kWh to only 2.14 kWh. In terms of marketing, this can affect negatively the customer's perception of the product, because no battery in the market offers that much different between nominal and usable capacity. Furthermore, in regards of the innovative BMS that is going to be implemented in the project and it is going to extend the lifespan of the battery, some competitive advantage must be taken. Therefore, **90% DOD** for the battery has been selected, having a usable capacity of 2.41 kWh per module and 9.65 kWh for the maximum capacity.

Regarding mechanical specifications, the battery pack is stored inside a boxing with a dimensions of 440x350x133mm. However, another boxing more aesthetical will be designed by Azolis in order to make the product look better. Hence, the important dimensions are the ones of the battery pack, which are 400x220x100 mm, and it has a weight of 13 kg. A 3D model is displayed in Figure 4.8 and a list collecting the main parameters of the battery is shown in Table 4.9.

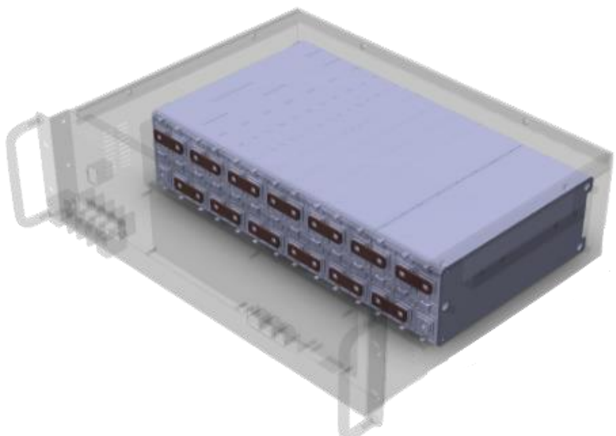


Figure 4.8. 3D model of the battery pack.

Chemistry	NMC			
Cell capacity	17.5 Ah			
Cell combination	3P14S			
Nominal voltage	51.1 V			
Nominal capacity	52.5 Ah			
Nominal energy capacity	2.7 kWh	5.4 kWh	8.1 kWh	10.7 kWh
DOD	90%			
Impedance	≤150 mΩ			
Certifications	CE, UN 38.3			
IP Protection class	IP21			
Operating temperature	-20 to 55 ºC (-20 to 0 ºC only discharge)			
Dimensions	400x220x100 mm			
Weight	14.5 kg			

Table 4.9. Main parameters of the battery.

4.3. BMS development and design

The BMS (Battery Management System) is a very important part of any battery because it determines its performance and ensures its safety operation. Regarding this project, it is not only that, but the key component of the RESS, the main differentiator, because of its innovative technology.

As stated in the strategy definition, more economic efforts are intended be deployed to incorporate to the RESS a management system that could provide added values to the performance of the overall system. Those efforts are focused in the balancing part of the cells, which at present is a critical point.

The lifespan of a battery is reduced through time because its capacity gets deteriorated as a consequence of disparity in individual SOC and SOH in each cell. In other words, each cell ages differently. For this reason, the battery stops charging or discharging as soon as one of the cells hits the upper or lower voltage limit, even though other cells may still contain energy or still have capacity to be charged. Thus, the performance of the battery is limited by the weakest cell, keeping energy trapped inside other cells that are performing properly. For example, in a document provided by the BMS manufacturer of a real-life example, a battery of an electric bus that they analysed, lost almost 50% of its initial autonomy because of a single cell out of 78 connected in series, as the following figure shows:

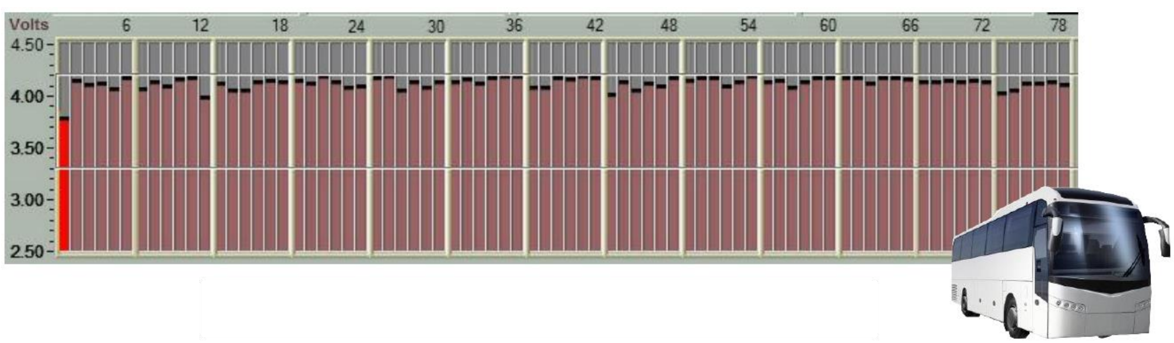


Figure 4.9. Performance of cells in a 50k€ electric bus battery. Source: BMS manufacturer.

This disparity in cells can be caused by many factors of different nature. No cell is identical to any other and may behave differently after a certain number of cycles, showing different SOC and SOH, caused by differences in capacity and internal resistance, as well as variations in leakage currents. Active balancing is the only way to fix both and maintain the battery at its maximum performance. Passive balancing, on the contrary, only equals the SOC of every cell by dissipating energy as heat until all the cells level their voltage, a process with a very low efficiency and high balancing period.

4.3.1. The search for added value

Accordingly, the efforts in the market research are going to be focused in active balancing BMS. Taking a look to the different active balancing methods in Table 2.2, **cell-to-cell** seems to be the alternative with better quality/complexity ratio to implement in a battery, since it has high balancing efficiency and fast operation. On the contrary, module-to-cell is relatively simple, but it “just” offers standard balancing quality and the high isolation voltage of the DC/DC converter can increase the cost. On the other hand, cell/module bypass provides very good quality and rapidity when balancing cells, but it is complex to implement and decreases the efficiency of the battery during operation.

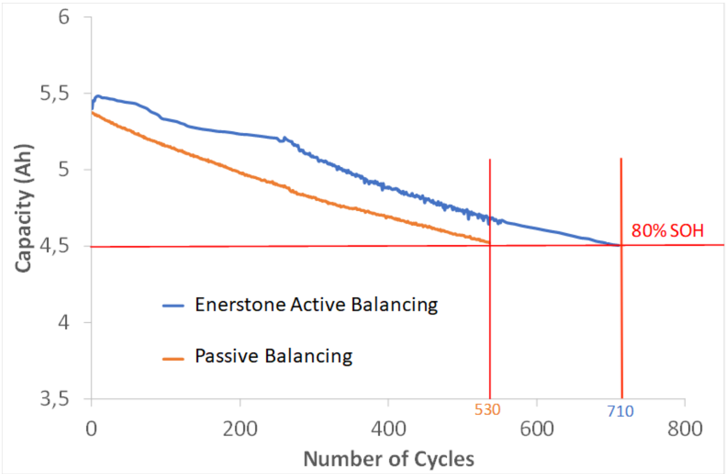
Actual cell-to-cell BMS work by transferring energy from the most charged cell to the adjacent ones with lower charge, levering the SOC of all cells in a module. The method works linearly, transferring charge from one cell to its neighbour cell, until it reaches the weak one and levels the SOC. The process is moderately fast. However, weak cells are not together in a battery, and it may take time and efficiency to level all the SOC of the different cells.

In this context, **Company 13**, a company founded in 2012 and stablished in Grenoble, France, is discovered. With their EVER Active Balancing System, they are aiming to preserve the factory specifications of a battery all along its useful life for the user. Winners of the KIC InnoEnergy EIT Venture Award 2013, they pack the know-how of three core competencies such as embedded software, power electronics and electrochemistry inside an electronic board that is connected to every cell of the module, extending the lifespan of the battery since the very beginning.

Their innovative added value is the creation of an optimized active balancing system that works cell-to-cell acting like a matrix, instead of linearly like the actual ones. In other words, it tackles all the weak cells of a battery at the same time, transferring energy from all optimum cells, no matter the position or distance at which they are collocated inside the battery. In this way, the balancing of the cells works way faster and more efficiently than any other. Using semiconductor technologies, as cell balancing typology they chose inductor base, because it is cheaper than transformer base and faster than capacitor base. According to the CEO of the company, their product is unique in the world and their know-how is patented.

Taking as example the electric bus battery shown in Figure 4.9, Company 13’s BMS would act not only in the first cell, which is the weakest, but only in all other cells that are not fully charged, making a continuous equilibrium of the SOC of every cell in the battery, thus improving the SOH.

The enterprise provided to Azolis a document of a similar battery regarding the actual project that they tested at their laboratories with a passive balancing BMS and with their BMS. This example is shown in Figure 4.10, showing the performance of their product tested in a small NMC battery of 200Wh for e-bikes. From the very first cycle, it can be observed a gain in capacity, due to the fact that the active balancing compensates the inter-cells differences in capacity and resistance.



Description
LiNMC Chemistry
2P10S – 5700 mAh 36 V – 200 Wh
Panasonic NRC-18650PF cells
Electric bike discharge profile max 2C (11 A)
Recharge C/2
Rest 30 minutes
Constant temperature
End of Life set @80% SOH

+34 % Extra Cycles with Enerstone

Conservative results :

- Power equipment limited @2C
- Ageing realized in climate chamber on open pack with low temperature stress

Figure 4.10. Ageing of two identical batteries.

Each battery ages in a different way and the results in Azolis system are still undefined, but the CEO of Company 13 advanced to the company that the results can be even more promising in bigger batteries where more cells and capacity are used. 30% of extra cycles in the actual project could be translated into 4 more years of operation under the same SOH of the battery, plus performing at an optimized level since the beginning. This offers a very big competitive advantage in terms of marketing, performance, customer service and warranty that Azolis could offer to the customer, since apparently the battery will work smarter and last longer than many others.

One of the main advices that the CEO of this innovative enterprise received as entrepreneur, is to go to the market as soon as possible. Being a scale-up company and looking to expand their market, the negotiations with Azolis were evolving nicely and easily, looking for a win-win partnership.

Currently, Company 13 is only able to provide the balancing and communication part of the system, or offer the whole BMS but acquiring the protection part from another company. Because of that, the protection part of the BMS will be demanded to the battery provider, Company 11. Cross-conversations were carried out in order to couple both systems. Company 11 would integrate already the BMS in the battery boxing, meanwhile Company 13 would provide their system ready to connect to the battery. The main specifications are listed down below. Current charge and discharge protections have been selected at that value to maximize the performance of the inverter, which offers its limit at that value.

The BMS specifications must be set at a proper level to ensure the proper overall performance of the RESS. It shall be the communication tool between battery and hybrid inverter. It must ensure that the battery respects the maximum current of the inverter and vice versa, and that the inverter stops charging and discharging the battery within the limits established of voltage range. Also it must inform to the inverter at any moment about the SOC of the batteries, so the EMS can take the decision of when to charge or discharge the batteries at any moment, optimizing the performance of the system. Regarding thermal protections, it also must collect the information set in Table 4.8 about different charging/discharging current rates at different temperatures. The main details about the parameters set in the BMS are shown in the next page, in Table 4.10.

Active Balancing current	2A
BMS cell configuration	14S
Communication protocol	Wi-Fi (wireless)
Cell over-charge voltage protection, delay time	3.9 V, 1s
Cell over-discharge voltage protection, delay time	2.75 V, 1s
Over current charge protection, delay time	> 60 A, 1s
Over current discharge protection 1, delay time	> 60 A, 1s
Over current discharge protection 2, delay time	≥ 80 A, 100 ± 50 ms
Short circuit current protection, delay time	≥ 300A, ≤ 300 µs
MOS over temperature protection	115ºC
Cell under/over charge protection temperature	-5ºC / 78ºC
Cell under/over discharge protection temperature	-20ºC / 78ºC
ENV under/over temperature protection	-25ºC / 75ºC
Consumption of both systems combined	≤ 25 mA, self-powered on the battery
Dimensions	280 x 87 x 5 mm

Table 4.10. Parameters of the BMS.

4.4. Hybrid inverter development and design

Hybrid inverters are starting to be very demanding with the technology advance in batteries. They are very suitable for storage applications because they combine solar inverter and battery inverter in one single product. The choice of the inverter will determine the input power from the PV array that the RESS can handle, the output that can be delivered to the household and the power that will be delivered to and from the batteries.

4.4.1. Preliminary definition of parameters

There are not many companies that develop hybrid inverters yet. Some of these companies offer hybrid inverters but with very low MPPT ranges of up to 120V, which are not suitable for this application. **MPPT ranges** must go above that value and up to 600V approximately, so many PV panels can be connected in series and work at low current to minimize losses, in a more efficient way. Besides, it is very important that the inverter has integrated dual MPPT instead of one, since this allows connecting arrays with different solar azimuth, tilt angles, string lengths, non-similar modules and provide better monitoring and performance. By this, PV systems can be designed in a more flexible way, lowering labour and installation costs. Concerning the **input** power admissible from the PV array, the higher the value, the better. Nonetheless, the higher will be translated also in the more expensive, so a value in between 5kW and 6kW could be the best in terms of quality/price, so up to 21 panels of 275 Wp could be connected to the system, for example.

Regarding the charging and discharging of the **batteries**, clearly it must be compatible with Lithium-ion batteries of 48V, accepting the voltage range of 42V to 58.8V of the battery provider. The maximum charge/discharge current must be set at a proper value to not stress the batteries and preserve their optimum operation. For this reason, maximum values close to 1C rate of the battery, 52.5Ah, should be chosen, but also offering a good power delivery to the household. A good range to set this parameter would be between 60A and 80A, in order to offer a power delivery between 3kW and 4kW to supply all loads connected in a household during an outage of the grid.

Taking a look at the **output**, as far as the target market will be focused in Germany and Europe, it must link the grid conditions of 230V and 50Hz. The maximum output should be bigger than the power delivered by the batteries, so when big loads are connected, the household can be feed by both the PV panels and the batteries.

Another important aspect that the inverter should include are **AC entries** as input power. In the unlikely event of a PV installation bigger than the input of the inverter, a solar inverter can be connected on those panels or strings that cannot be assumed by the hybrid inverter, and reconnect them to the AC entry, so more input can arrive to the battery, even though in a less efficient process.

As recommended by Company 13, the BMS manufacturer, the better communication protocol between the inverter and the BMS is wireless communication, so the installation of the RESS is simplified. The option of adding Wi-Fi represents a very small amount of capital to the project, as it will be justified in future sections.

Table 4.11 summarises the preliminary parameters that are intended to be set in the hybrid inverter selected, always depending on what it can be found in the market.

PV input power	5kW – 6kW
MPPT Voltage range	120V – 600V

Battery compatibility	Lithium-ion
Battery voltage range	42V – 58.8V
Charge/Discharge current	60A – 80V
Output	230V, 50Hz
Output power	Around 5kW
Communication protocol	Wi-Fi

Table 4.11. Preliminary parameters definition for the hybrid inverter.

4.4.2. Sourcing and partnership establishment

Almost all the hybrid inverter companies in the market were contacted. The features and specifications that each of them offer are not very distant, with a portfolio ranging from small hybrid inverters to big ones. To sum up, the two negotiations that evolved the furthest will be discussed. The two companies involved are Company 15 and Company 14.

The specifications of the hybrid inverters offered in their portfolio for residential applications is shown in the next page, together with their corresponding prices.

In regards to Company 14, the most suitable inverters are **Product 1** and Product 2, since those are the only ones with 2 MPP Trackers, a very important point argumented previously. However, Product 2 has very high input parameters that make it more expensive and that may be oversized for the majority of customers; those high parameters are not needed regarding the average PV sizes of a household. Taking a look to Company 15, their inverters only differ in the input and output power. The most suitable would be between Product 3 and **Product 4**, but for just 40€ more, the second would be better.

Comparing both models, even though the maximum DC input power is almost the same, the inverter of Company 15 has wider MPPT voltage range. This means that some more PV panels, actually around two, can be connected in series to the string/s of the PV array. The difference, though, is not as significant as the fact that Company 15 inverters do not have an AC entry where more power can be connected, either from the grid or from those extra PV panels that the system cannot handle.

In regards to other parameters such as the battery voltage range, Company 15 acts confined to the battery voltage range of Company 11. The upper limit of 58V can be adjustable to make it until 58.8V, meanwhile the range of the inverter of Company 14 has some more window. The output power is also very similar. Company 15 inverters can be installed outdoors, but as far as the battery selected can only be installed indoors, Company 14 is as valid as its competitor in the RESS designed.

Regarding the warranty, Company 15 offers two more years than Company 14. Nonetheless, the price and not having AC entries are factors more decisive and of higher weight.

Table 4.12. Hybrid inverter specifications from Company 14 and Company 15. Confidential.

Going on with the negotiations, dealing with Company 15 was very pleasant and close, as one of their sales manager in Europe and Africa visited the office of Azolis for dealing about further partnership as inverter provider for some of the projects that the company is intending to run in Africa and Middle East. The predisposition and proactivity to cooperate in the RESS project was set at a very high level and comfortable. They even lower the initial price of their products to the ones shown in Table 4.12 in order to compete against Company 14.

However, **Company 14** was offering a **unique added value** in between all other manufacturers. Their **Business Model is ODM** (Original Design Manufacturer), they are actually the largest ODM UPS/inverter supplier by number of units produced. They are very good at innovation, technical design and production, but they do not perform branding, neither involve marketing and sales in the global market. All the products they sold are with customers' brand name. They produce after receiving orders (Built to Order) and do not keep finished product stock. They do not apply neither marketing fee because those are branding activities performed by their customer. Therefore, they do not have so-called distributor network. In terms of **marketing strategy**, this is very advantageous, since the company can use Company 14's product under the brand Azolis, with our own boxing design. Because of this and the similar performance of both inverter brands, **Company 14**, with their inverter Product 1, was selected as partner for developing this RESS project. Besides, Company 14 hybrid inverter can be connected with other models in parallel, so **the system can be expanded** to up to 8 modules with two inverters and a total storage capacity of 21 kWh.

4.5. EMS & future Community platform idea development and design

The main intention with the EMS development and design is to place at the service of the customer all the technology involved in the management of the RESS. Through remote maintenance and monitoring via platform through app, computer or display in the system, the customer must be able to see and explore the different states of the system through a day, study the historical data and analyse the decision making on how to configure the installation. Through machine learning, the system must perform a state of the art of energy functions, studying the weather forecast of the corresponding location and analysing the consumption profile of the household to act in the most optimised way possible. By this, the system will be able to better know when to store and when to use the batteries, how much energy must be stored during each time of the day, etc., to perform a smart home automation and maximize the ROI of the customer. Also, the software will incorporate further improvements with updates.

Since this system is supposed to increase the price of the entire RESS significantly, the customer will have the opportunity to choose a more basic EMS, in charge only of managing the flows of energy without all those premium features, decreasing thus the final customer price by means of thousand/s euros.

For this purpose, a partnership established by the CEO of Azolis has been set. The company chosen is Company 16, a Moroccan/French start-up with expertise as control software developer for solar plus storage systems. As stated in their webpage, Company 15 develops and markets the first artificial intelligence-based energy management software that enables industrial and commercial buildings in Morocco and Africa to produce and consume to reduce their energy bill by 20%. According to their CEO, their software can be easily adapted to residential application. With headquarters in Paris and Casablanca, their office in Morocco is just some kilometres away from Azolis. Due to the good relationship between both CEOs, from Azolis and Company 15, a free sample for testing in the prototype phase will be provided to Azolis.

In future stages, the possibility of creating a Cloud Community in where customers can share their self-produced energy and become more independent will be studied. By means of blockchain process and a monthly fee, the customers will be able to share the surplus of energy to serve other members that cannot generate energy due to bad conditions. For every kWh shared, the customer will receive a financial compensation above of the feed-in-tariff level. Whenever the customer receive energy from the community, he/she will have in return electricity prices much lower than the ones of the grid providers.

4.6. Assembly of the RESS

The assembly of the system, as previously exposed, will be performed in Morocco. Company 17, based in Morocco, will be in charge of that. Expert in industrial electronics, Company 17 specializes in all kind of electronic and mechatronic assemblies and subassemblies. Mainly oriented in exporting, the company service includes not only assembling, but also manufacturing, project management, raw materials purchasing and logistics management.

All the processes and products carried out by Company 17 are certified by ISO 9001, quality management systems. With a plant of 4500m^2 and more than 200 employees, their capacity production will be able to handle the assembly industrialization of the RESS designed for a first commercial stage.

4.7. Warranty conditions definition

The warranty is one of the main factors that influences a customer when purchasing a RESS or another. The more kWh warranted, the more appealing will the system be for the client. After determining all the components that shapes the RESS, one thing is clear: the battery will perform at a higher level during its lifetime than many others competitors, and will last longer that the ones of similar characteristics, thanks to the high quality performance of the balancing of the BMS. Therefore, Azolis needs to take advantage of this feature.

Taking a look to the warranty conditions of the main competitors, many of them offer two conditions with energy capacity constraints. a Normally the condition that happens before is 10 years under a capacity constraint of about 60% of original capacity. With a well sized system, the customer will cycle the battery less than once per day, meaning in ten years less than 3600 cycles. When asked to the sales manager and engineers of Company 11, they assured their battery can assume those 3600 cycles keeping more than 60% of the original capacity with no problems, even under real conditions. Therefore, taking advantage of the BMS, there will not be capacity constraint in the warranty, since it is supposed that the battery will operate at optimized performance during its lifetime.

By this, the warranty conditions equal the best one in the market of E3/DC, offering 10 year warranty without constraints. Waiting for the test results, assuming a moderate gain in the lifespan of the battery of 20%, those 3600 cycles with more than 60% of the original capacity could be translated in more than 4300 cycles with still more than this 60% of capacity. This is translated into **12 years**, the years that have been determined for the warranty of the RESS designed, overcoming any competitor in the market. Taking into account that the battery must be installed indoors, usually it will work at temperatures close to the ideal one shown in Figure 4.6, more than being installed outdoors.

Moreover, customers will enjoy of a free scalable period of the product of 6 months, in which they will be able to expand/reduce the modularity of the system, if through the platform they observe that the RESS is oversized or undersized.

The negative point in the RESS warranty is the inverter. As far as Azolis is not an inverter manufacturer, a warranty of only 5 years will be offered to the customer. Therefore, the warranty conditions will state the following points:

- 12 year warranty for the batteries with no constraints.
- 5 year warranty for the inverter.
- Maintenance, repair and replacement of parts under warranty conditions.
- Free scalable period of 6 months.

4.8. Aesthetical design

The aesthetical design of the system is very important from a marketing point of view. As far as the system is going to be installed indoors, a good aesthetical design is key in order to make it comfortable for the vision. It has been tried to make it look as a furniture, so it can be installed everywhere in the house close to the dashboard of the house, as well as in the garage or in the living room. Next figures show the design and how it could fit in a standard household living room. This is only a preliminary visual design performed by the project manager and author of the dissertation. The idea will be forwarded to Company 18, a French company with expertise in design that the CEO of Azolis already contacted. The manufacturing of the boxing, once the designed is defined, will be carried out in Morocco by Company 17. The dimensions of every module are 460x350x150 mm (WxDxH), with natural ventilation to prevent overheating of the batteries, and the ones from the inverter are 445x120x500 mm. The system will offer the option to be wall-mounted, module by module, since they are quite small in size.

Figure 4.11. Aesthetical design of the RESS. Source: own-made from various Google images.

4.9. Overall Product Overview and Value Chain

After the justification of the choice in strategy followed, features, parameters and elements of the RESS, the system can be placed in the market regarding its competitors, in both performance and price. First of all, to provide an idea on how the overall RESS should be coupled, the following figure shows a scheme about it. A general datasheet of the overall system is also shown in the following table.

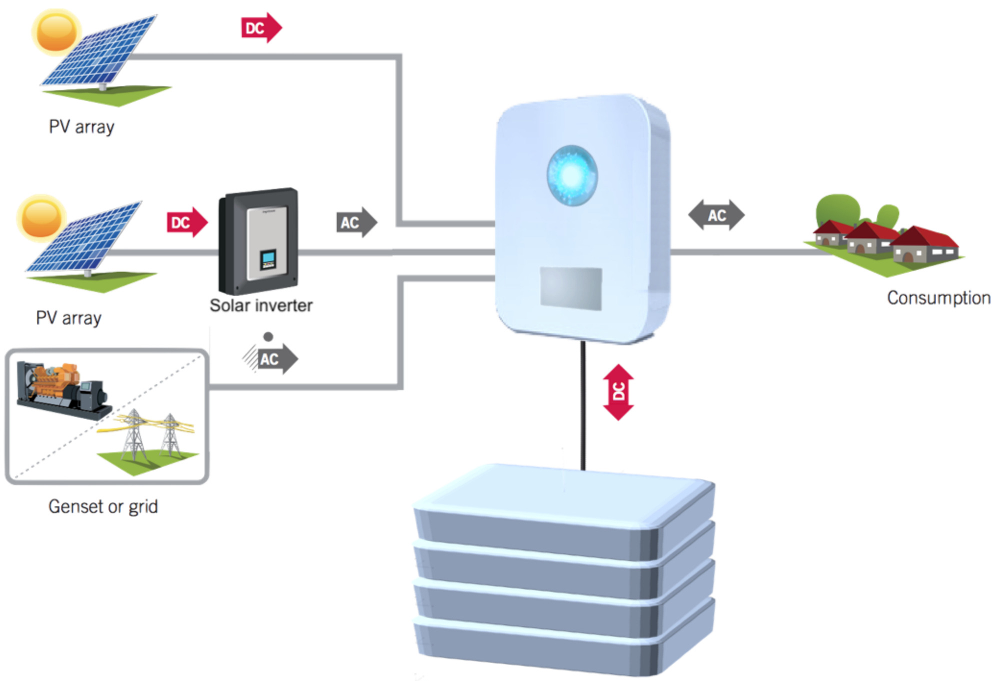


Figure 4.12. Scheme of the overall RESS. Source: own-made from various Google images.

Regarding Table 4.1, where the level of features that Azolis intended to achieve in regards to competitors was shown, these is now where the product is positioned regarding the market.

- **Modularity**. The RESS has modularities available ranging from 1 to 4, offering 2.68kWh, 5.36kWh, 8.04kWh and 10.72kWh. The hybrid inverter allows the connection of another inverter in parallel, so up to 8 modules can be connected in total, increasing the capacity to up to 21.44kWh. The system is very scalable and satisfies the main market volume with just one inverter, achieving a high level of modularity, equal to SolarWatt and overcoming competitors such as Tesla, LG Chem, or E3/DC.
- **Compact design**. The size achieved per battery module is very compact and small (46x35x15cm). Pending from evaluation from the design company Company 18, the system will offer the possibility to be either wall-mounted or just compacted as Figure 4.11 shows, aesthetically looking like one piece of furniture in the house. With this feature, the customer will not have to worry about where to install bigger systems or aesthetically not good looking like the many companies offer.

- **Warranty conditions**. As stated before, it is almost compulsory for the company to offer the best warranty in the market, since the system counts with one of the most advanced balancing technologies in the market and must take advantage of it. Prior to the testing of the RESS, the intention is to offer 12 years of warranty, offering the best battery warranty of the market.
- **Performance**. In terms of performance, all the system has been configured to operate properly and in line with all the components. With no need to add external elements to the system (all-in-one), each component perfectly communicates with each other and operates in line with the setup of the others. Furthermore, the battery will keep capacity ratios close to the fabric settings during all its lifetime due to the innovative BMS, offering an overall high performance at any time. The high-tech EMS will also contribute to improve the user experience and to optimize the operation of the RESS. Furthermore, the system provides good power delivery with just one single module and provides emergency power supply in case of grid outage until batteries are totally discharged. Taking into account all these characteristics, companies such as LG Chem, Sonnen, SolarWatt, Varta and some others, have been surpassed in terms of performance.
- **Lifespan**. Prior to the release of the product into the market to check its real performance, the RESS designed could offer for the first time a residential storage application that leads to profitable investment for the customer. The warranty provides 12 years of operation, time in which the capacity ratio is expected to be still higher than 60% of the original capacity. The lifespan of the batteries could be extended until more than 20 years under a good performance, which can lead to a payback on the investment for the customer.

In the next page, the main parameters of the RESS designed are listed. This data is the one that will be delivered in the commercial datasheet to the client and will be posted in the webpage and in distributors' portfolio.

INPUT	Max. PV Input Power	6500 W			
	Max. PV Voltage	580 V			
	Nominal PV Voltage	360 V			
	MPP Voltage Range	120 – 500 V			
	No of MPP Tracker	2			
	Max. Input Current	2 * 13 A			
	Start PV Voltage	150 V			
	AC Input Voltage Range	170 – 280 V			
	Max. AC Input Current	40 A			
BATTERY	Cell Chemistry	NMC			
	Nominal Capacity	2.7 kWh	5.4 kWh	8.0 kWh	10.7 kWh
	Nominal Voltage	51.1 V			
	Operation Voltage Range	42 – 58.8 V			
	Max. Charging/Discharging Current	60 A			
	Max. Charging/Discharging Power	3 kW			
	DOD	90%			
	Communication	Wi-Fi			
	Certificate	UN 38.8, CE			
OUTPUT	Max. AC Output Power	5500 W			
	Rated Output Voltage	230 V			
	Rated Output Frequency	50 Hz			
	AC Nominal Current	23.9 A			
	Max. Backup Supply Power	3 kVA			
	Max. Auto-switching Time	< 3 seconds			
SYSTEM	Max. Efficiency (PV-Battery-Grid)	≥ 88 %			
	Max. Efficiency (PV-Grid)	≥ 95 %			
	Max. Efficiency (Battery-Grid)	≥ 93 %			
	IP Protection Class	IP21 (Indoor)			
	Operating Temperature Range	-20 ~ 55 ºC (-20 ~ 0 ºC only discharge)			
	Humidity Range	0 – 90 %			
	Altitude*	1000 m			
	Battery Dimensions, Weight	460 x 350 x 150 mm, 16 kg			
	Hybrid Inverter Dimensions, Weight	445 x 120 x 500 mm, 17 kg			

Table 4.13. General datasheet of the RESS designed.

4.9.1. Value chain of the RESS

Down below, Porter's value chain diagram is shown regarding the value chain of the RESS designed, from the beginning of its lifetime with the reception of the components, until the end of its lifetime with the recycling of the battery. The recycling service of the battery has not been announced until now, but it is a feature that the company is thinking to implement in ten years, when batteries start to arrive to the end of their lifetime.

Figure 4.13. Porter's value chain of the RESS. Designed with template from SlideHunter.

5. Prototyping stage and tests

After defining every of the components and features of the RESS, the next stage is to develop a prototyping phase in which various tests can be performed in order to verify that every component of the product works accordingly to the parameters set, to try the effects of the BMS in the battery lifespan and also to follow-up the results through the EMS.

Therefore, a planning on how to develop this stage must be established. Accordingly, the next elements are demanded to the partners:

- Company 11. 7 battery modules, 1 of them with the whole BMS (balancing, protection and communication part) and 6 just with the BMS protection part.
- Company 13. 6 BMS (balancing part) to test within the 6 battery modules ordered with just the protection part.
- Company 14. 5 hybrid inverters, 1 to be lend to Company 17 so they can carry out some reverse engineering, and 4 to be used under different tests.
- Company 15. 1 EMS sample to test within one complete system comprised by 4 modules.

The purpose of ordering these specific number of elements is to conduct the following tests:

- MVP (Minimum Viable Product) Test. A simple test carried out in the office with one battery module with Company 13 BMS and one hybrid inverter will be coupled to verify the proper functioning of the system. Taking advantage of the solar panels and the PV structures that Azolis keeps stored in the warehouse, a small PV array comprised by 6 panels from Jinko, each of 280Wp, will be installed on the rooftop and connected in parallel to feed the batteries through the hybrid inverter. A small resistance will be connected to dissipate the energy from the battery, and during the day the battery module will be fully charged and discharged to simply verify that the system works and to better understand its performance.
- Test on BMS performance. IRESEN (Institute Research Energy Solaire et Energies Nouvelles), one of the top Institutes in Africa focused on R&D, agreed on giving the opportunity to Azolis to test the battery in their laboratory facilities. The test will consist on evaluate the impact of Company 13's active balancing BMS compared to the passive balancing of Company 11, to conclude the real impact of the innovative BMS in the battery performance. The test will be carried out by cycling the different BMS in separated battery modules many times a day, until both of them reaches 80% of the original capacity.

- Full test on full system. The last of the tests will consist on testing the RESS with 4 modules, with Company 13's BMS, connected to the inverter with the EMS installed, to check the overall performance of the system and how it manages the energy flows within the 4 modules.

In regards to the impossibility of implementing those tests because the components of the RESS were not going to arrive when expected (due to external problems from the project manager), some simulations were attempted to be performed. Matlab (Simulink), PVSyst and PSIM, softwares designed to simulate this kind of systems, were used. Unfortunately, none of them includes hybrid inverters in their extensive library, neither an active balancing BMS as the one used in the product. In other words, the technology employed in the RESS could not be found in any of those programs. Only similar battery characteristics, with the combination of solar inverter and battery inverter could be simulate. At the end, it did not make any sense to simulate a different system than the one developed in this project, so no results yet can be shown. Besides, for simulating just 3 real seconds on the project, the softwares took too long, more than 20 minutes in average.

On the other hand, all possible efforts to prepare and leave everything ready for the testing in the prototyping phase and further steps were made, such as agreements with IRESEN to access to their facilities, or with Company 17 for the industrial process of assembling the BMS with the battery and to have ready all the wirings needed to couple the entire system.

In next section, the development of the Business Model and Business Plan to implement the battery in the market will be discussed.

6. Business Model

In this section, it will be presented how the company is positioned within its industry's value chain, and how it organizes its relations with partners and customers to generate profits through the Business Model Canvas. It is a tool that consists on a visual chart containing the essential elements that describe a firm's or product's value proposition, infrastructure, customer and finances. The BMC has been evaluated and adviced by professionals of the GCIP (Global Cleantech Innovation Program) 2018 that took place in July 2018, Morocco.

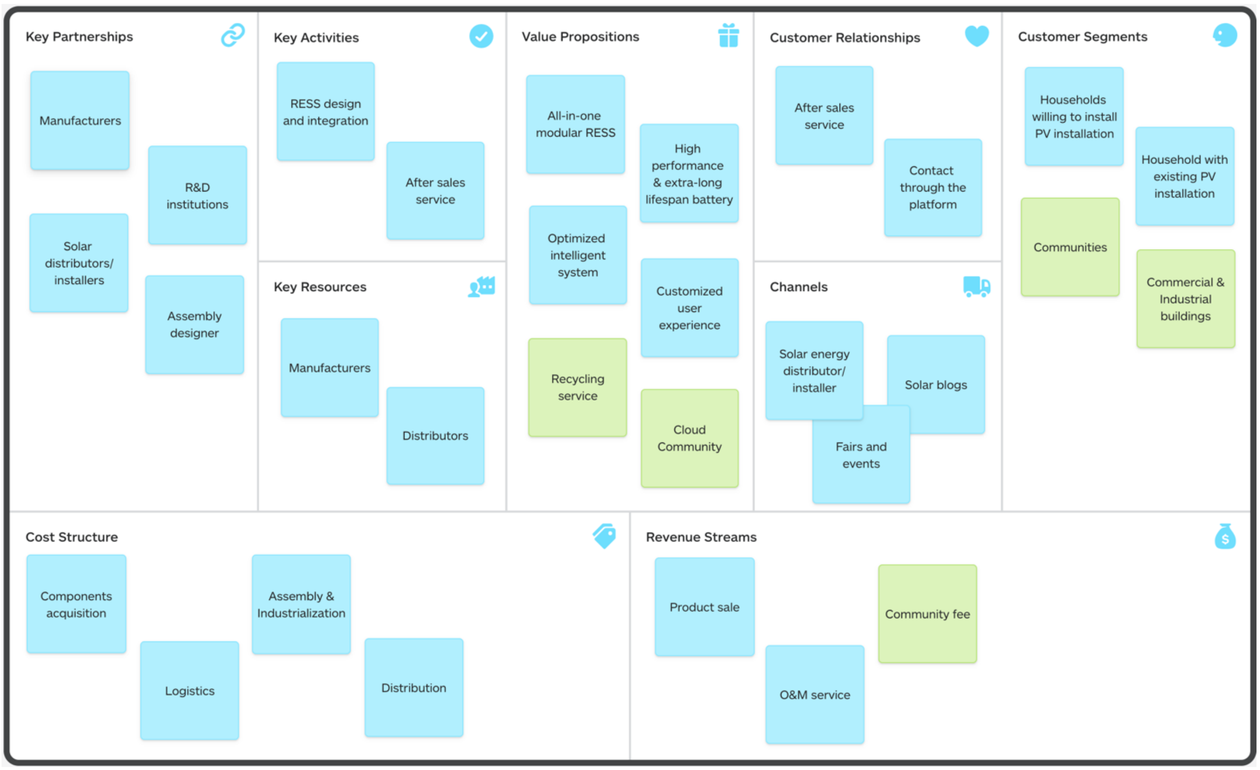


Table 6.1. Business Model Canvas. Developed with Strategyzer.

It can be distinguished two colours on the labels of the Canvas: the blue ones represent the key features of the business model, meanwhile the green ones represent future expansions that could be very interesting to add to the business model when the project reaches more mature levels. Hereafter, an explanation for each of the sections and labels is developed, for a better understanding.

Customer segments. As it can be inferred, households are divided into two different segments: the ones without PV array that are willing to install solar panels with storage back-up, and the ones who already have

PV panels and want to install a storage system. As it was shown in Figure 4.1, the first segment almost doubles the second in terms of demand.

To this first segment, Azolis could offer not only the battery, but also the PV array, providing to the customer the whole package. To the second segment, the customer will be asked about the option of removing the solar inverter already installed, in exchange of improving the overall efficiency of the system (thus, less energy conversions will be needed). By this, the company could keep second hand solar inverters for those customers whose solar installation is bigger than the input capacity of the RESS, connecting them to the AC entry of the RESS, and thus increasing the stored energy (scheme shown in Figure 4.12).

In further and more mature stages, since the system is scalable and expandable, new customer segments such as residential communities or commercial and industrial buildings can be added to the Business Model, thus expanding the market.

Value propositions. The value propositions refer to the value that is brought to the customer segments stated before. The most obvious one is an all-in-one modular RESS that perfectly adapts to the needs to the customer, providing them with the whole installation and with the energy capacity that suits them the best in regards to their consumption and PV array size. The most differentiating value is the higher performance and longer lifespan that the RESS offers during its entire lifetime, above the average in the market. The customer can enjoy free solar energy from what it could be the first RESS that leads to a return on the investment, thanks to its innovative and unique BMS worldwide. Another important value is the customer experience that the intelligent RESS provides through the platform, being able to check and track all the data and customize certain parameters.

In further stages, when the company achieves a fleet of customers, a Community could be develop in which clients could share their energy surplus and get remunerated by means of a cryptocurrency, that could exchange afterwards when the PV panels do not generate energy due to bad meteorological conditions, always at a lower price than the electricity from the grid. Furthermore, in about more than 10 years, when the batteries are close to the end of their lifetime, a recycling service will be offered to the customer, to preserve the ecological value of the product.

Customer relationships. The customer relationship is one of the points in which the company wants to focus the most. A good after-sales service can play an important role in customer satisfaction and retention, generating loyal customers and spreading the power of word of mouth. Through tracking of the data registered in the platform, any malfunctioning of the system will be reported, so the customer can get advice on how to improve or set some parameters of the battery. Besides, under warranty conditions, any damaged component must be replaced as fast as possible.

Channels. The cannels to reach new customers are diverse. The main one will be through solar distributors' portfolio and/or solar installers. As a start-up, it is almost mandatory to reach the market through third parties, due to lack of resources. Another channel very important is to be present in solar blogs. Nowadays, this is an online tool very frequented by users looking for critical reviews about any kind of solar systems from experts or other users with a wide knowledge in the topic. Currently, solar blogs are innumerable, both international and by country. Therefore, is a very useful tool to spread the marketing of the company. The last channel will be though fairs and events related to solar technologies, a classical chance to expose the solution and awake curiosity.

Revenue streams. The revenue streams in this Business Model are very simple to understand. They will mostly come from product sales. Also, from possible future modifications in the modularity of the product, mainly expansions in the energy capacity. In future stages, the possibility for the customer to join the Community by means of a monthly quote is especially interesting for the company, because it will add a, important new monthly revenue stream.

Key partnerships. There many partnerships that are key in the development of the project. First of all, the manufacturers. Each of them provide every single component that shapes the RESS and without their cooperation there would not be any product. Secondly, solar distributors and installers, under the task of assuring that the product arrives to the market and to the customer. Thirdly, R&D institutions, such as IRESEN, which will provide their facilities to test this innovative product. Last, but not least, the partnership with the assembly designer, who will be in charge of the industrialization of the product, to later export it.

Key activities. The key activity of the company is the design and integration of the RESS presented in this project. Besides, the constant research for possible improvements and further partnerships than can improve the quality of the product and services. The other main activity of the company, equally important, will be the after sales service to the customer, explained in customer relationship, fulfilling all their needs and demands and providing advices to improve the performance of the RESS.

Key resources. The key resources of the company in this Business Model are redundant with key partnerships. In this case, the most appreciated resource is the partnership with the manufacturers, who provide the components of the system, and the solar distributors/installers, who are the channel to arrive to the market. The rest is the know-how of the market and technology, the engineers behind the project and the capital from future funding.

Cost structure. The cost structure of the product can be associated with its value chain. First of all, the acquisition of every of the components, its importation, the assembly and industrialization of the RESS, the outbound logistics and in the last stage, the distribution costs.

7. Business Strategy

In this section, the implementation and execution strategy of the company's plan for market penetration and expansion are discussed. As well as the BMC, the Business Strategy has been followed up by experts of the GCIP Morocco 2018 coming from Silicon Valley, USA.

7.1. Milestones prior to commercialization

Previously, the main milestones of the management of the project prior to the commercialization of the product are shown in the following Gantt chart. This diagram is a tool used for illustrating a schedule that helps to plan, coordinate and track specific tasks in a project. In this one, just the key tasks are shown, without entering in the details of each of them.

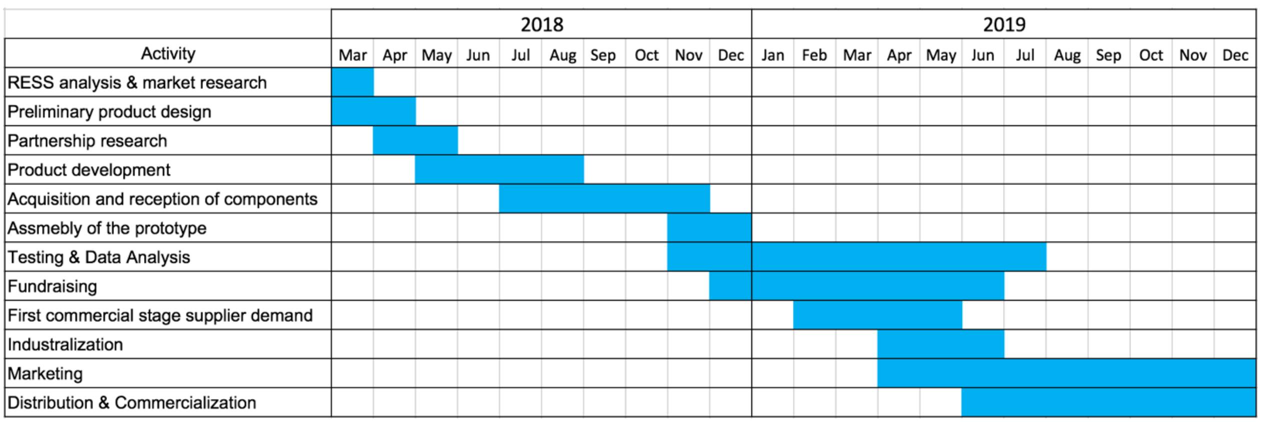


Figure 7.1. Gantt chart of the management of the project. Source: own.

The most critical stage is the Testing & Data Analysis, which will determine the compatibility in the integration of each of the components of the RESS, as well as the overall performance and the effect of the innovative BMS in the system. The second most critical point will be the fundraising needed to develop the first commercial stage. Once the first tests are performed and the data analysed, the next half-year will be focused on raising fund. With the promising results of the innovative BMS working in the RESS, it should be easier to attract investors. Afterwards, the first demand of the components to the manufacturers to develop an initial commercial stage could be realised. The objective is to start marketing the product in the second half of 2019, fulfilling previous pre-orders launched by the first customers.

7.2. Market penetration

As stated in some sections of the dissertation, the region chosen to penetrate the market for the company will be Germany. Reasons are very clear, since currently Germany accounts for approximately 70% of the European residential storage market for both MWh installed and economic market volume, according to Figure 3.5. Germany is the country that leads the worldwide market, reaching at the end of August 2018 the number of 100,000 residential storage installations for the first time, with a forecast of 200,000 for 2020 [28].

Furthermore, national legislation is pushing towards the sector by means of subsidies and incentives that started already in 2013. In 2016, the subsidy program was extended to 2018, and it has been allocated around EUR30 million by the Federal Ministry of Economic Affairs and Energy [29]. It is the most promising market in Europe by far, so a rapid penetration is of critical importance. In Figure 7.2, it can be observed how the trend in the evolution of the market grows increasingly year by year.

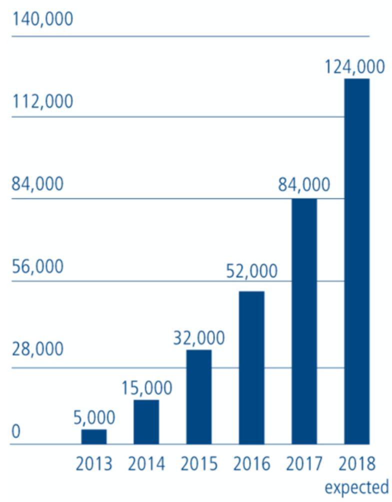


Figure 7.2. Development of residential energy storage in Germany

The beachhead, so the most strategic region where from which to launch the commercial stage of the business, is going to be the South of the country, either close to Stuttgart or to Munich, two of the two economical motors of the country. Both cities are located in the areas with more annual global irradiation (Figure 7.4) and higher GDP per capita (Figure 7.3). From a strategic point of view, these two should be the areas with more potential customers, since RESS are not a cheap investment and require high global irradiation to optimize its performance.

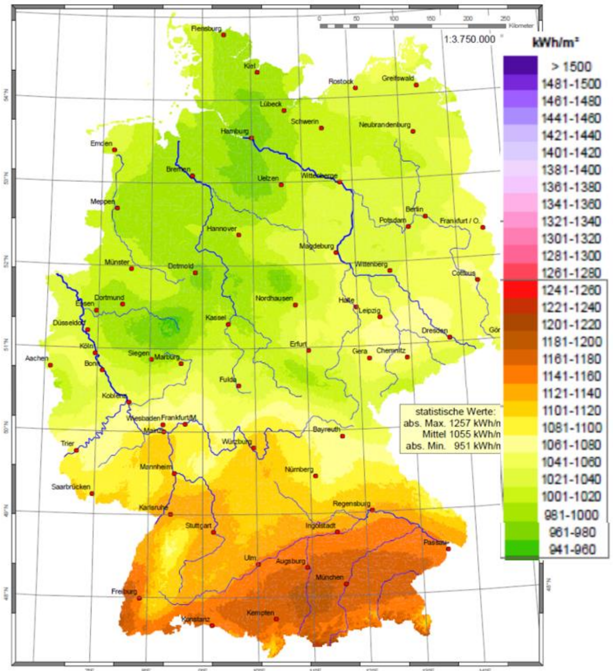


Figure 7.4. Annual global irradiation in Germany averaged over 1981-2010 [5].

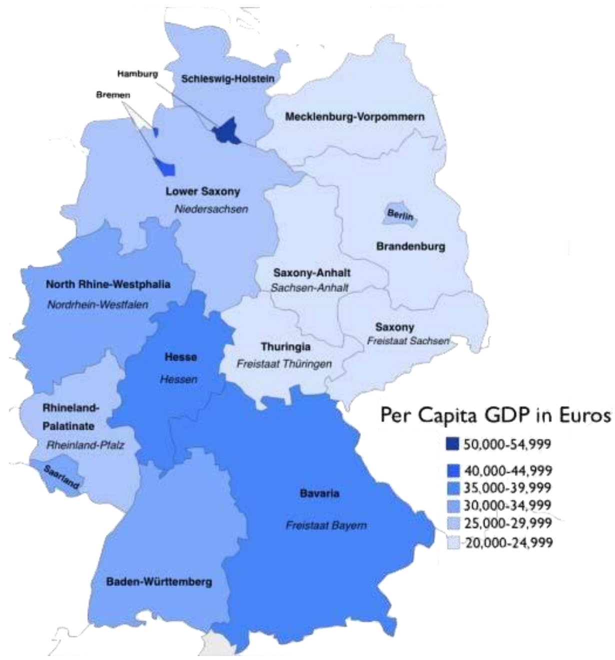


Figure 7.3. GDP per capita in Germany per state. [39].

7.3. TAM, SAM & Target Market

Taking into account that the customer segment targeted are households from developed countries without already existing storage installation, having or not PV panels, the Total Addressable Market for residential storage is uncountable, if it is considered worldwide. Therefore, the TAM is delimited to the countries where residential storage application is having a certain impact. Taking a look on the number of households in Europe and Germany [30], Australia [31] and USA [32], and the total number of RESS installed on those areas shown in Figure 3.4, an estimated number of potential customers (households without PV + storage installation) can be calculated.

Focusing on Europe and Germany (country with approximately 70% of the European market), with the available data in Figure 3.5, the average storage capacity in kWh/household and average price in €/RESS can be calculated. Thereupon, the number obtained can be extrapolated to the total million households without PV + storage installation (potential customers) in Europe and Germany. The results are shown in the following table:

	Europe	Germany	Australia	USA	TOTAL
Number of households (in millions)	221.3	40.7	9.5	126.2	357.0
Number of installations (in thousands)	160	124	69.7	30.5	169
TAM in potential customers (in millions)	221.1	40.5	9.4	126.2	356.5
TAM in GWh	484	85	-	-	-
TAM in million €	600 000	98 000	-	-	-

Table 7.1. TAM for RESS per region in 2018.

According to Stromvergleich [33], the acceptance rate of German households to install PV panels is about 72%. As reported by EnergySage in a survey [34], 74% of residential solar power customers were considering or were interested in installing energy storage. This accounts for a total of 53.28% of households willing to install residential storage solution, in the German country. Accordingly, the forecasted SAM is calculated and presented in Table 7.2. Both TAM and SAM are expected to follow an almost linear trend during time with propensity to slowly decrease, since the trend in Germany on number of households is increasing, but the potential customers are decreasing as soon as the market is expanding.

	Germany
SAM in potential customers	21.58
SAM in GWh	45.3
SAM in million €	52 200

Table 7.2. SAM for RESS in Germany.

From there, a realistic approach has been followed to determine the target market. The objective is to achieve the 0.05% of the SAM in a 4-year horizon, once commercialization is initiated, which would account for around 10800 customers, translated into a 3.6% of the forecasted share of the market. To calculate this, a linear trend of 50000 yearly new installations of RESS has been supposed until 2022, with a total number of 300,000 systems in the market. The evolution of the expected target market is shown in the following table:

	2019	2020	2021	2022
Target market (No. of customers)	35	575	2900	7300
Target market in MWh	0.16	2.68	18.76	58.40
Target market in THOUSAND €	82	1405	6735	17075

Table 7.3. Target market for the company.

In order to be close to this approach, marketing will be very important. To be present in the maximum possible number of solar blogs is a must, so experts can detail reviews about the system and people can get to know the brand and the product. Normally those reviews are very focused in performance, warranty conditions, and price, which are outstanding features of the RESS designed. The results shown in last row in Table 7.3 can be understood by reading the next section.

7.4. Cost structure, revenue generation and sale price of the RESS

The overall RESS developed and designed has been revealed, but not yet its cost structure. It is disaggregated down below, regarding official prices provided by partners. The price of the EMS is still undefined, since a free sample is provided in the prototype phase. Other parameters such as the assembly of the product or distribution costs are estimated, since those are the following steps to define once the pieces arrive. The overall costs are shown for the biggest combination of the RESS with 10.72kWh in 4 battery modules, since the costs of other companies have been always referred to the module closer to 10kWh.

Battery (with protection part of BMS)	520€/module (for orders of 25 units)
Battery Importation costs (FOB)	275€ (for orders of 25 units = 13.75€/unit)
Hybrid inverter (including importation FOB)	730€/inverter (for orders of 20 units)
Wi-Fi card for inverter communication	30€/inverter
BMS (Balancing & Communication parts)	300€/module
BMS Importation costs (FOB)	60€ (for orders of 100 units)
EMS*	750€/system
Boxing manufacture*	40€/module
Industrial assembly*	175€/system
Manufacturing costs	**5070€/system**
€/kWh	**315€/kWh**
Commercial margin (40%)	**+3380€/system**
Sales price for distributors	**8450€/system**
Distribution costs (35%)*	+4500€/system
Final customer Sales price estimation range	**12000 to 14000 €/system**
€/kWh	**1100 to 1300 €/kWh**

*Estimated costs with non-official available data

Table 7.4. Cost breakdown of the RESS.

Those are official prices given for the prototype phase, but they are supposed to decrease when ordering big quantities, since manufacturers manage prices in regards to quantity demanded. Exportation costs from Morocco to Europe have been neglected, since importation costs from Asia to Morocco account approximately for 65€ for a RESS of 4 battery modules and 1 hybrid inverter. Depending on sophistication, the EMS manufacturer suggested that prices can oscillate from 500€ to close to 1000€ per system, so an average price has been calculated. The commercial margin has been defined to represent an increase of 40% in the manufacturing cost, but can be modified depending on the real costs that have been estimated.

The agreement conditions with the distributors will be very important. Since the company, as an average start-up, will not have high capital resources at the beginning, the idea is to negotiate a high percentage over final sales for the distributor and a low fee to pay for its service. By this, the distributor will be remunerated at a higher level than average, and more efforts will be done to sell our product. If those conditions are achieved, it would be perfect for the penetration of the product into the market. The estimation of the percentage to be paid per product over the monthly, trimestral, semester or yearly quote to the distributor cannot be performed, as this is a variable depending on how many RESS are sold in the market in each period of time.

Since there are many factors undefined, and some factors could be size from an optimistic point of view, a range on the estimation on final price has been assessed with some cost plus pricing added. The range to position the product, actually, makes sense regarding to the official data available. All in all, this estimated RESS final customer price is very close to the value that was intended to reach in Figure 4.3, where Azolis wanted to be targeted since the beginning. Therefore, it can be concluded that the company will compete against the companies with biggest share in the market, offering slightly higher performance (because of the innovative Management system integrated) and warranty conditions, at a slightly lower price.

In order to make the system more affordable and accessible to more customer segments, the option to include the EMS will be given. This will give the company the flexibility to offer a basic product around 2000€ cheaper (because the cost of the EMS increments after commercial margin and distribution costs).

The next table reflects the main data for each modularity.

	1 module	2 modules	3 modules	4 modules
Manufacturing costs (€)	2510	3360	4220	5070
In €/kWh	936	627	525	473
Commercial margin	1673	2240	2810	3380
In €/kWh	624	418	350	315
Sale price (€)	6430	8620	10810	13000
In €/kWh	2400	1610	1345	1212

Table 7.5. Manufacturing cost, commercial margin and sale price of the RESS, per modularity.

It can be observed that the higher the modularity, the more cost-effective is the product for the customer, in terms of €/kWh. On the contrary, sales with lesser modularity, the more profitable is for the company. Nonetheless, the option that most probably will provide the best-selling numbers will be the one with 3 modules, followed by the one with 2 and the full RESS with 4, regarding energy needs of the main volume of the market, as it is explained hereafter.

7.5. Financial results

With the data gathered, financial results can be performed. For that purpose, it must be known on average which of the modules will be sold with more frequency than the others. Taking into account that the average consumption of a German household is about 3300 kWh/year [35], 9kWh/day are consumed on a daily basis during the year. Regarding to the self-consumption rates shown in Figure 3.1, only 40.5% of that energy can be supplied from an optimised PV installation without storage, so the rest of energy will remain to be stored with our RESS, accounting for 5kWh. However, as the PV installation usually is not sized to satisfy all the consumption demand from a house, more energy is supposed to be stored, so probably the RESS with 3 modularities and 8kWh capacity will be the most demanded one. Because of the results just commented, the system with 2 modularities and 5.4kWh of energy will be the second most demanded, followed by the full system and the one with just one battery module. Therefore, it will be assumed that 40% of the sales correspond to 3 modularities, 30% to 2, 25% to 4 and only 5% to one module in the RESS.

The results are divided by quarter of years, for more precision and detail, and are set in a 4-year horizon.

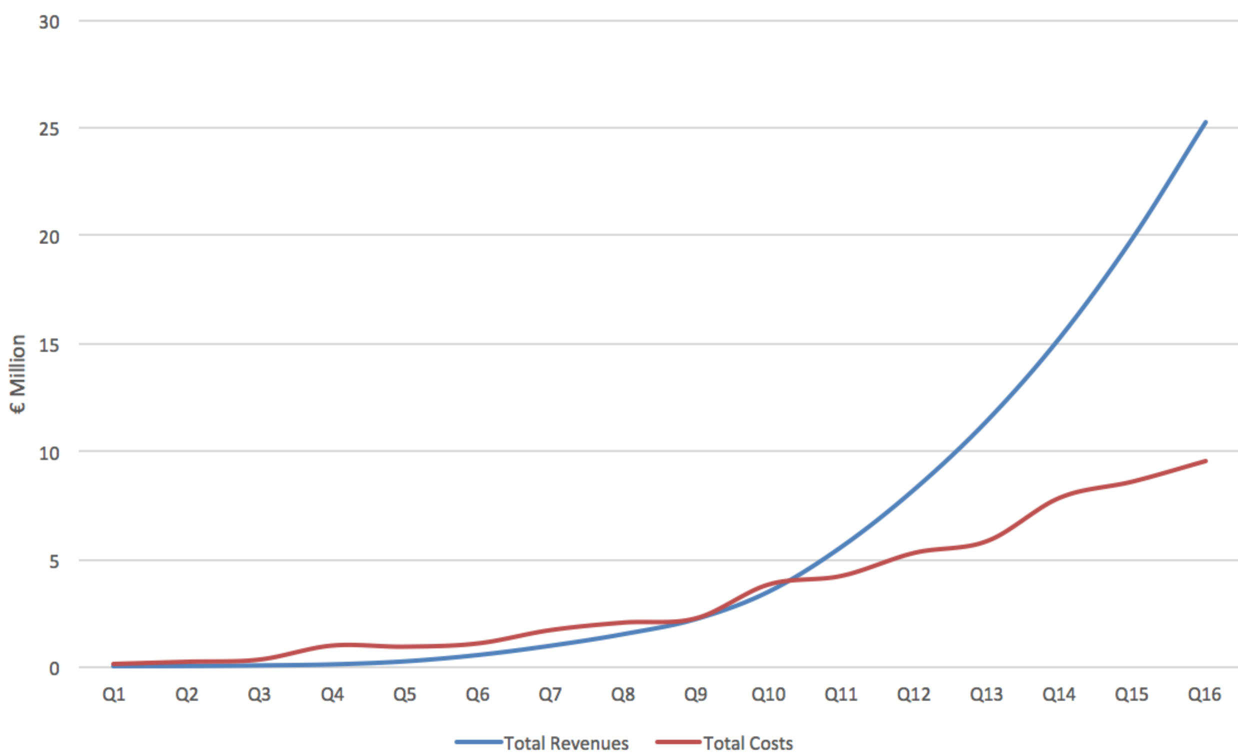


Figure 7.5. Total revenues VS. Total Costs

As it can be inferred, the costs are always higher than the revenues until the half of the 2nd year of commercialization. Not only the purchase of the components for the first commercial stage and its industrialization, but also the expansion and the establishment of the company in Germany, forces that until X quantity of sales are not achieved, the revenues do not surpass the costs of operation of the company. Furthermore, this is a Business Model in which its main revenue stream strongly depends on the sales force, so it takes time until revenues start to take-off, since the product needs time to get known in the market.

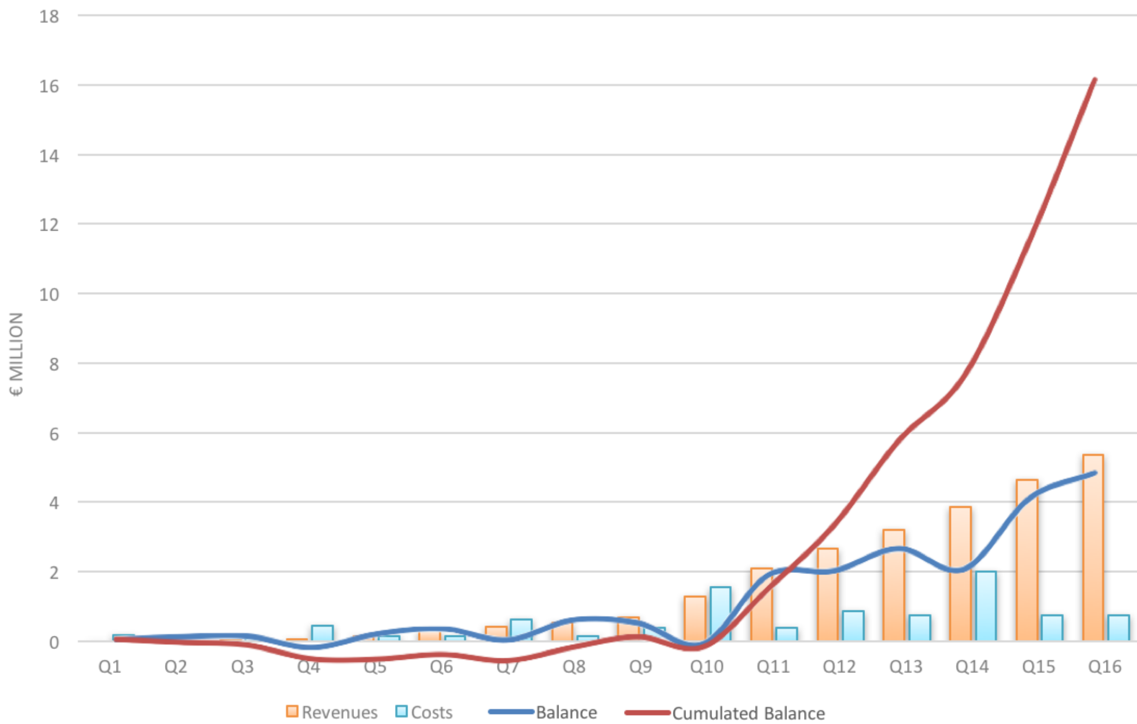


Figure 7.6. Balance and cumulated balance.

In this figure, the balance and cumulated balance are shown with the total revenues and cost from the last chart. Both balances oscillate during time, due to big amounts of components purchased of the RESS meanwhile sales are increasing. The cumulated balance stays always in negative value until the half of the 2nd year of commercialization, when revenues overcome costs for the first time. After this period of time, it is supposed that the high performance of the RESS starts causing some marketing effect and commences to gain reputation in the market, thus making sales to increase exponentially. By the end of the 4th year, the cumulated balance would reach around 16M€, with a very positive trend.

The results shown can be concluded as a realistic approach; this market is demonstrating that allows companies to expand and grow fast and rapidly. For example, Sonnen, the company with currently biggest share in the market, was founded in 2010 and after six years of operation was already registering revenues of 42€ million, in 2016, with a total funding amount of 145.5 M€ in 2018 [36]. Similar cases happened with E3/DC or SolarWatt.

7.6. Future improvements

In the future, for when the company is more mature, already some improvements in the performance of the RESS are being defined to add more value on the solution.

Briefly, one of them has been already mentioned, which consists in the creation of a Community in between the users of the company where the customer can exchange surplus of kWh to other clients in exchange of cryptocurrency remuneration for buying a cheaper energy from the grid and coming exclusively from renewable energy.

The other one is to establish another company in order to increase the self-consumption rate to ratios close to 100%. This company is Company 19, established in France and specialised in providing home automation devices that increases the self-consumption from PV panels up to 20%, without the need of installing batteries. Through data monitoring and state of the art of every load of the house, the system is able to process data and optimise the household consumption with forecast predictions and home automation. A first approach was made to offer the possibility of a future partnership, and the feedback was positive.

8. Conclusions

In this document, the design and product development of a RESS have been developed, together with its business model and business strategy to penetrate the market. Overall, it can be stated that, pending tests and evaluation, the product is expected to offer higher performance and longer lifespan over the time, far above market average, at an average price. Moreover, financial results show a promising scenario in a market growing exponentially.

Taking a look to the business part, especially on the market analysis and on the results estimated in the previous section, it can be concluded that is a must to launch the product and go to the market as soon as it is possible. The exponentially favourable market trends and the healthy market share where no company is showing predominance over others, constitute a context favourable to the entry of new companies. As shown by the financial analysis, the solution appears to be very promising and profitable, showing a payback on initial investments by the half of the 2^{nd} year of commercialization. Revenues are expected to reach cumulative values of 25 million € within a 4-year horizon scenario, with around 16 million € in cumulative balance. This scenario can look optimistic, but as stated before, the market has shown with other companies that allows rapid growth and expansion in short periods of time. All these evidences given support the idea that now is the moment to invest in this specific market.

With regard to the technical side of the RESS, very positive conclusions can be extracted. The partnership with the BMS manufacturer has been a successful deal, since it provides the main differentiation of the product when comparing it to the market. Active balancing cell-to-cell by means of a matrix interconnection in between cells, allows the BMS to act very efficiently, very fast and in a continuous way in the balancing of the cells, levering the SOC at any moment. By this, the lifespan of the product can be extended around 20-30%, which is translated into 4-5 more years of maximum performance. Thanks to this extremely low deterioration, the RESS can offer the best warranty conditions in the market, surpassing all competitors.

Not only that, but taking a look on the rest of parameters designed and defined of the RESS, the entire product keeps an overall optimal performance. It offers very good ranges of modularities and energy capacities, capable to adapt to a wide variety of customers regarding their specific energy needs. In some cases, customers must buy external components to the RESS purchased, and not always matches at 100% in terms of performance. The company's RESS designed provides an all-in-one product in which every component has been configured to work together in the most optimal possible way. Even the RESS with one battery module can provide good power delivery, and the hybrid inverter switches rapidly to off-grid mode, assuring power back-up in case of grid outage. Last but not least, the high performance of the EMS software will optimise all flux of energy within the RESS and provide to the client a high customer experience, through consumption data processing, weather forecast and remote control and monitoring.

All in all, with regard to the objectives set in the introduction, it can be concluded that:

1. As stated, the design and product development of the RESS have been successful, offering a modular all-in-one product, with a theoretically outstanding performance and long lifespan, that perfectly adapts to the customer needs.
2. A good business strategy and BMC have been defined to enter the market. The feedback from experts of the GCIP and financial expected results give evidence of that.
3. The reasons on why to invest now and why in this specific market are wide. Exponentially increasing trends, good share competition and rapid and fast growth allowed by the market in the last years are more than enough evidences of a big window of opportunity.
4. The process behind a project management has been assimilated. There are hundreds of variables to take into account and each finding contributes to the creation of strong idea generations. Every decision making must be supported by solid arguments, and alternatives must be always prepared in case of unforeseen events and setbacks. Many are the difficulties overcome that are not exposed in the document, and the author can strongly affirm that this experience has been very rewarding and useful for developing a promising professional career.

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