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INTERNATIONAL TRANSFER AND CANCELLATION OF THE GUARANTEES OF ORIGIN ISSUED FROM ENERGY GENERATED BY THE PHOTOVOLTAIC SYSTEM

PÄIKESEENERGIA VÄLJASTATUD PÄRITOLUTUNNISTUSTE RAHVUSVAHELINE ÜLEKANNE JA TÜHISTAMINE

MASTER THESIS

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DECLARATION OF AUTHORSHIP

I hereby declare that this thesis is the result of my own independent work and it has been presented to the department of Electrical Power Engineering and Mecharonics of Tallinn University of Technology in order to claim a master's diploma in Distributed Generation. This thesis has not been presented before to claim a degree in engineering sciences or engineering.

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Abstract:

The present thesis aims to study the mechanism of the certification of the renewable energy production known as Guarantees of Origin, namely its issuance, the transfer between the European countries focusing on Estonia and Portugal and its cancellation. This work includes the sizing of the self – consumption photovoltaic (PV) system in Portugal and the study of the ways of the cancellation of the issued Guarantees of Origin, including the possibility of its transfer to Estonia. The introduction of the Directive 2009/72/EC obliged all the EU Member States to guarantee that electricity suppliers specify to the final consumers the contribution of each energy source to the overall fuel mix over the previous year. The Guarantees of Origin must be used to prove the share of renewable energy in the total electricity delivery to the customers. With acquiring the Guarantees of Origin is possible to say that the consumed energy originates from the renewable energy sources. With the objective to enable the international transfer of the Guarantees of Origin between the countries there was created *Association of the Issuing Bodies* (AIB). However, Portugal, which has been its member since 2003, left the association by the end of 2015. Currently the only possible way to transfer the Guarantees of Origin from Portugal to Estonia is by using the mechanism known as *Ex – domain cancellation*.

There is very unclear legislative base concerning the transfer and the cancellation of the Guarantees of Origin in Portugal, especially which were issued for the self – consumption of the produced energy, so more studies must be conducted in this area.

Keywords: AIB, Guarantee of Origin, Photovoltaic Energy, Photovoltaic Self – consumption

Lõputöö kokkuvõte

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Sisu kirjeldus: Käesoleva magistritöö eesmärgiks on uurida toodetud taastuvenergia sertifitseerimise mehhanismi, mis põhineb päritolutunnistustele. Kirjeldatakse päritolutunnistuste väljastamist, ülekandmise ja tühistamise võimalusi Euroopa riikide vahel, keskendudes Eesti ja Portugali näitele. See töö sisaldab päikeseenergia tarbimise süsteemi projekteerimist Portugalis ja väljastatud päritolutunnistuste tühistamise võimaluste uuringut. Euroopa Direktiivi 2009/72/EÜ alusel kehtestati, et kõikidel Euroopa Liidu liikmeriikidel on kohustus näidata ära iga energiaallika osakaal aasta kogu energiatarbes. Päritolutunnistusi saab kasutada taastuvenergia osakaalu tõendamiseks elektri tarnes klientidele. Päritolutunnistuste ostmisel saab öelda, et tarbitud elekter pärineb taastuvatest energiaallikatest. Päritolutunnistuste rahvusvaheliseks ülekandmiseks on loodud 2001 aastal *Association of the Issuing Bodies (AIB).* Portugal on olnud selle ühingu liikmeks alates 2003. aastast, kuid lahkus ühingust 2015 aasta lõpus. Käesoleval hetkel ainus võimalik viis päritolutunnistuste ülekandmiseks Portugalist Eestisse on läbi mehhanismi, mida nimetatakse "Ex – domeeni tühistamine". Portugalis on siiamaani väga ebaselged õiguslikud alused päritolutunnistuste rakendamises, eriti päritolutunnistuste tühistamisel, seetõttu on põhjendatud põhjalikud uuringud selles valdkonnas.	
Märksõnad: AIB, Päikeseenergia, Päritolutunnistus, Päikeseenergia Omatarbimine	

Resumo

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Descrição do conteúdo: A presente dissertação pretende estudar o mecanismo de certificação de produzida energia renovável, conhecido como Garantia de Origem, nomeadamente a sua emissão, a transferência entre os países europeus com foco na Estónia e Portugal e o seu cancelamento. O objetivo da presente dissertação é dar a visão global das possibilidades existentes de transferência de atributos de energia renovável através do mecanismo conhecido como Garantias de Origem, nomeadamente entre Portugal e Estónia. Este trabalho compreende igualmente um dimensionamento de um sistema fotovoltaico para autoconsumo em Portugal e o estudo das formas de cancelamento das emitidas Garantias de Origem, incluindo a possibilidade de sua transferência para a Estónia. A introdução da Diretiva Europeia 2009/72/EC obrigou todos os Estados – Membros da União Europeia a garantirem que os fornecedores de eletricidade especifiquem os seus consumidores sobre a contribuição de cada fonte de energia. As Garantias de Origem comprovam a contribuição total das energias renováveis no fornecimento de eletricidade aos clientes. Com a aquisição das Garantias de Origem é possível provar que a energia consumida provém de fontes renováveis. Com o objetivo de permitir a transferência internacional de Garantias de Origem entre países foi criada no ano de 2001 a *Association of the Issuing Bodies* (AIB). Portugal aderiu à mesma em 2003, no entanto, abandonou – a no final de 2015. Deste modo, atualmente a única forma possível de transferir Garantias de Origem entre Portugal e Estónia é através do mecanismo conhecido como *Ex – domain cancellations*,

Conclui-se que, atualmente existe uma base legislativa muito pouco clara sobre a implementação de Garantias de Origem em Portugal, em particular sobre emissão das Garantias de Origem pela energia autoconsumida, pelo que devem ser realizados mais estudos nesta área.

Palavras – chaves: AIB, Autoconsumo, Energia Fotovoltaica, Garantia de Origem

Contents

Assignment

Topic of thesis:	**International transfer and cancellation of the Guarantees of Origin issued from energy generated by the photovoltaic system**
Student:	**Aleksandra Krivoglazova 153452AAHM**
Speciality	**Distributed Generation**
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Student (signature)

Supervisor (signature)

Justification of Topic

The generation of the photovoltaic energy in the Southern countries such as Portugal is more advantageous since it has a lot of solar energy resource. With the implementation of the certain mechanisms defined in European legislation, it is possible to transfer the produced renewable energy attributes from one European Union (EU) Member State to another, such as Estonia, which does not have sufficient solar energy resource. At the European level, such mechanism is known as a Guarantee of Origin, which enables to trace the origin of the consumed electrical energy.

Writing the thesis in University of Porto gives the opportunity to combine the knowledge of the sizing of the photovoltaic system for self – consumption in Portugal and the knowledge of the transfer and commercialization of the produced clean energy attributes in Estonia. The legislation at the Portuguese level concerning the implementation of the Guarantees of Origin and its transaction mechanisms is still not clearly defined and requires more investigation. This thesis aims to give an overview of the existing possibilities for the renewable energy attributes transfer between the countries and will provide its implementation on example of the photovoltaic energy production for self – consumption in Portugal and its value commercialization in Estonia. Moreover, there would be studied the ways of the issuance of the Guarantees of Origins for the self – consumed photovoltaic energy and its cancellation.

Purpose of Work

The general purpose of this thesis is to study the mechanisms of the renewable energy attributes certification and transfer between the EU Member States, namely Guarantees of Origin, taking the advantage of solar energy generation in the Southern countries and its commercialization in the Northern countries. More specifically this work aims to the PV system sizing and energy production for the self – consumption and the possibilities of the PV energy attributes transfer between Portugal and Estonia.

List of Problems

- Study of the photovoltaic self – consumption in Portugal
- Sizing of the photovoltaic system for the self – consumption in Portugal
- Study of the Guarantees of Origin
- Study of the procedures of the produced renewable energy attributes transfer between Portugal and Estonia
- Study of the commercialization process of the green energy products

Research methods

The data used in this thesis is obtained from the scientific articles, statistical databases, books on the planning and installing of PV systems, the Portuguese and Estonian Directives and Internet. For the sizing of the PV system were used the software *PVsyst*, *SketchUp Skelion* and *Excel*.

Foreword

This thesis was elaborated in University of Porto, Department of Electrical and Computer Engineering during my exchange studies in Portugal in Erasmus+ framework. The topic for the thesis was offered by the professor Cláudio Monteiro. The topic was chosen because I have always been interested in renewable energy promotion and I had a unique opportunity to combine the knowledge received in my home university in Estonia and in University of Porto in Portugal.

The work was supervised by professor Cláudio Monteiro from Porto University and by professor Juhan Valtin from Tallinn University of Technology.

This work was supported by Erasmus+ scholarship.

In this space, I am going to express my sincere acknowledgment to all those who supported me throughout this work. I want to thank my supervisors for all their guidance, support and their availability in the elaboration of this work that have led to the present thesis. Big word of appreciation for my dear family, especially my parents Jelena and Aleksandr and to my brothers and a grandmother, for the way they have instilled the joy, motivation and the confidence to fulfil my dreams not only in this final stage, but during all my academic journey.

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Finally, a big word of appreciation to my Estonian and Portuguese colleagues and my friends for all the given support and positivism during this process.

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List of Abbreviations and Symbols

AIB – Association of Issuing Bodies

CHP – Combined Heat and Power

DGEG – Directorate – General for Energy and Geology

EECS – European Energy Certificate System

EEGO – Guarantee of Origin Issuing Entity

EMA – Electricity Market Act

ERSE – Energy Services Regulatory Authority

FIT – Feed – in Tariff

GOs – Guarantees of Origin

MPP - Maximum Power Point

NLEG – National Laboratory for Energy and Geology

OMIE – Iberian Energy Market Operator

PEX – Cross – linked Polyethylene

PRI – Period of Return on Investment

RECs – Renewable Energy Certificates

RES – Renewable Energy Sources

RTIEBT – Technical Rules for Low Voltage Electrical Installations

SERUP – Electronic Registration System of the Production Units

TGCs – Tradable Green Certificates

TSO – Transmission System Operator

UPAC – Self – consumption Production Unit

Introduction

Climate change mitigation is one of the main challenges facing the world today. Various strategies were developed for the carbon mitigation both at European and national levels [1]. European Union (EU) set a goal that 20% of the total European energetic consumption by 2020 must come from renewable energy sources (RES). This objective has been confirmed with the European Directive 2009/28/EC, so – called "Climate Action and Renewable Energy Package". The main targets by 2020 include [2]:

- 20% of the consumed energy must originate from RES
- 20% of reduction of carbon dioxide (CO_2) emissions compared to 1990 levels
- 20% increase in energy efficiency
- 10% share of energy from RES for transport

With the objective to stimulate the development of renewable energy generation, many countries have issued the corresponding policies [3]. The Figure 1 shows the growth of the share of renewable energy in gross final energy consumption in Estonia and Portugal, and a share of renewables in electricity production [4].

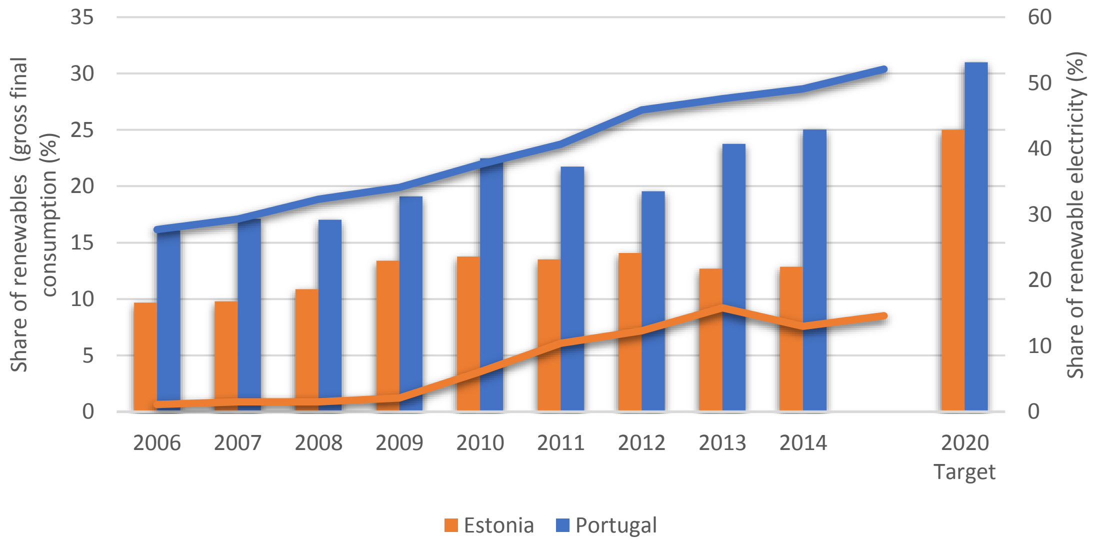

Figure 1 Shares of renewable energy in gross final energy consumption in Estonia and Portugal and the National targets for 2020. The lines represent the shares of renewable electricity in gross electricity consumption (Source: Eurostat)

According to Estonian National Renewable Energy plan, by 2020 is estimated to achieve 25% of the renewable energy share in the gross final energy consumption [5]. In Portugal by 2020 is estimated to achieve 31% of the renewable energy share in the gross final energy consumption [6].

The technology development and innovation driven by EU and national policies, over the last few years enabled to increase the use of renewable energy technologies with the significant cost reductions. The business and households can produce and consume their own electricity. Through the process of "self – consumption", the passive consumers are becoming active "prosumers" [7]. Among various renewable energy technologies, photovoltaic (PV) technology attracts more attention due to its high potential to increase the share of renewable energy production [2]. The main reasons for the significant growth in PV electricity is a rapid technological progress, cost reductions and relatively short project development time.

According to the Directive 2009/72/EC of the European Parliament and Council, the Member States must guarantee that electricity suppliers specify to final customers the contribution of each energy source to the overall fuel mix of the supplier over the previous year in a clearly comparable way [8]. However, electricity flows to the final consumers from a mixture of energy sources, from all the power stations that are connected to the power system, so the physical energy is almost impossible to track. With the objective to permit the power producers to manifest to the final consumers in a uniform way that their energy was produced from RES there were introduced Guarantees of Origin (GOs) [9]. The GO is a clear tracking mechanism for the electricity attributes, which is issued for the disclosure and transparency purposes. Moreover, there the possibility to transfer the GOs and sell the attributes of the produced green energy from one Member State to another.

Currently the legislative framework concerning the GOs and its transactions is not fully clear, especially at the Portuguese level. The purpose of this thesis is to give an overview of the existing possibilities for the transfer of the renewable energy attributes between the Member States on the example of PV energy attributes transfer between Portugal and Estonia. The theoretical part of this work is divided into two parts. The first part includes the overview of the solar energy resource in Portugal, the study of the necessary components for the self – consumption photovoltaic system creation and the current situation of the electrical energy self – consumption in Portugal. The second part focuses on the renewable energy attributes transfer between the European countries and the implementation of the GOs scheme. There are analyses of the main aspects to consider when importing the GOs from Portugal to Estonia and its commercialization in Estonia. The practical part of this thesis is also divided into two parts. The first part includes the main steps for sizing the self – consumption photovoltaic system and the second part focuses on the commercialization of the produced PV energy attributes.

1. Photovoltaic Energy

The use of the energy generated by the sun is inexhaustible in the terrestrial scale of time, both as a source of heat and light and can be considered as one of the most promising energy alternatives to meet the challenges of the current energy demand growth. There are two major types of technologies to harness solar energy:

- **Solar thermal technology** uses directly the heat coming from sun to heat the water, using the sun collectors or vacuum tubes to capture the heat from the sun and transfer heat to the liquid
- **PV solar technology** converts directly the solar rays into electricity using the solar panels

PV is a promising type of solar energy technology that has received public attention in the last decade. In 1999, the total worldwide installed PV power was 1 GW and in 2013 the total installed PV capacity increased until 138 GW. In 2014, around 40 GW of PV capacity was added, reaching the global total of about 177 GW. Since the beginning of the new millennium Germany is a leader in the PV energy employment with their progressive renewable energy policy, leading to a large national solar market with 43% and 38% of the PV system installed worldwide in 2010 and 2014, respectively [10].

The main advantages of solar energy:

- Solar energy does not create pollution during its' use. The pollution from the manufacture process of the necessary equipment for the construction of the solar panels is fully controllable
- The power plants require the minimal maintenance works
- Solar panels are becoming more powerful and at the same time their cost has been declining, making PV technology increasingly an economically viable solution
- The solar energy is a great solution for the remote or hard – to – reach places, because its small – scale installation does not require huge investments in the transmission lines

The main disadvantages of solar energy:

- The variations in the amounts of the produced energy in accordance with the climatic conditions (rain, snow) and the absence of production during the night, requiring the energy storage devices for the electrical energy produced during the day in the places, where the solar panels are not connected to the power transmission network

- Medium and high latitude locations suffer abrupt drops in production during the winter months due to the lower daily availability of solar energy. Moreover, places with frequent cloud cover tend to have daily variations in production according to the degree of nebulosity

There are many well – developed and broadly used technologies for electricity generation, such as conventional fossil fuel and hydropower that are currently far more widely used than PV technology. The main question is how PV systems can penetrate the world's electric supply in competition with these alternatives [11].

1.1 Solar energy resource in Portugal

Solar radiation is the Earth's energy source, which provides heat energy needed for various chemical and physical processes in the atmosphere, ocean and land [12]. From the point of view of utilization of solar energy for electrical energy production, the estimation of global radiation for a certain region is essential.

For example, in Portugal the global irradiance is almost two times greater than in Estonia. The Figure 1.1 depicts that the annual global irradiance in Estonia is 1 140 kWh/m^2, and in Portugal: 2 160 kWh/m^2 [13]. Thus, the PV energy usage in Estonia is less profitable than in Portugal.

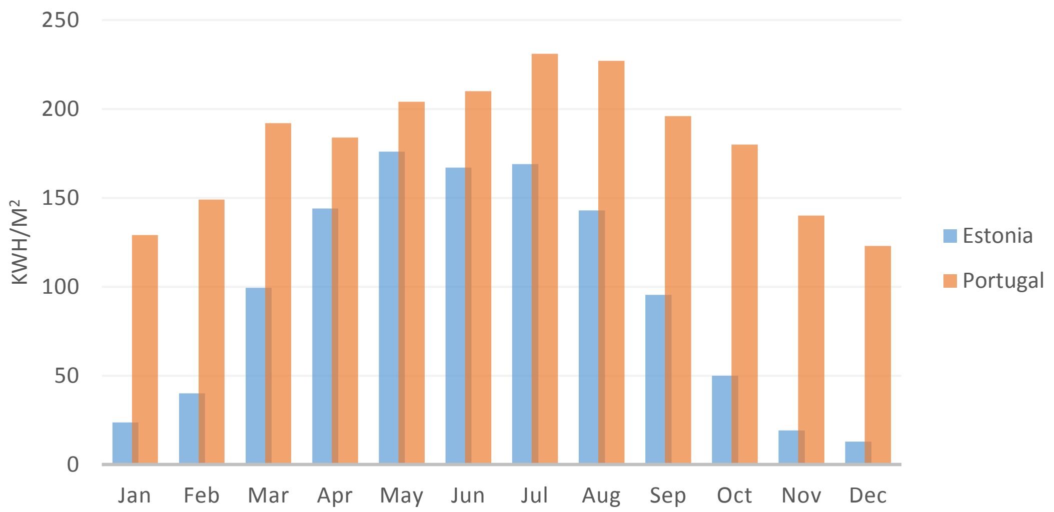

Figure 1.1 Average sum of global irradiation received by the solar modules (Source: PVGIS)

The following Figure 1.2 allows to assess the PV potential in Portugal. In 1997, the total installed PV capacity accounted to 1 MW. In 2015, the PV installed capacity was 451 MW. By the end of September 2016, the use of PV technologies allowed to achieve 796 GWh of electricity generation, whereas the region of Alentejo accounted for 38,7% of the national PV production. Since 2014 nine PV concentrating plants were installed, with the total installed capacity of 9 MW [14].

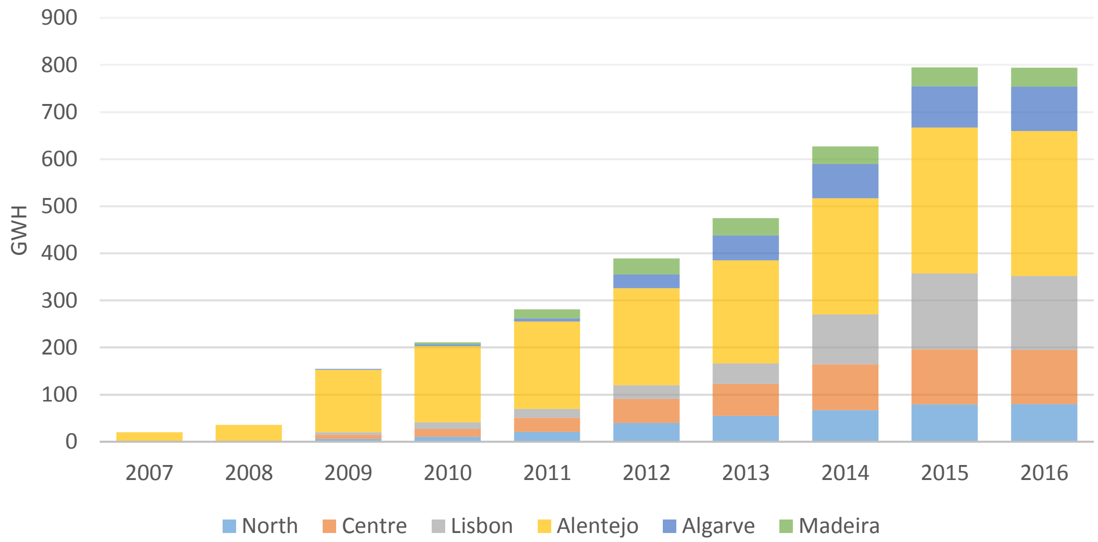

Figure 1.2 The PV electricity generation per region in Portugal (Source: APREN)

Alentejo is the region in South – Central part of Portugal. In this region, in the municipality of Moura near the village of Amareleja, there is located a PV solar power plant with the total installed capacity of 46,41 MW. The Amareleja solar power plant was built in 2008 in 9 months, occupying 250 hectares and its average annual production is around 93 GWh [15].

1.2 The main components of Grid – Connected System

Grid – connected PV systems are designed for the parallel operation with the electric energy grid which functions as an energy store. A typical grid – connected PV system is constituted of the following components [16]:

- PV modules (multiple PV modules connected in series or parallel with mounting frame)
- PV array junction box (with protective equipment: string diodes and fuses)
- Inverter
- Direct current (DC) and Altering current (AC) cabling
- DC main disconnect switch

1.2.1 Photovoltaic modules

The photovoltaic cell is the fundamental unit in the energy conversion process. This device is composed of the semiconductor material in which the electrons, when exposed to the sunlight, are becoming excited and turned into an electrical current. Nowadays exist many different types of PV technologies (Figure 1.3), however it is possible to distinguish two principal groups: the PV solar cells that are made of crystalline silicon and the solar cells that are made using thin – film technology.

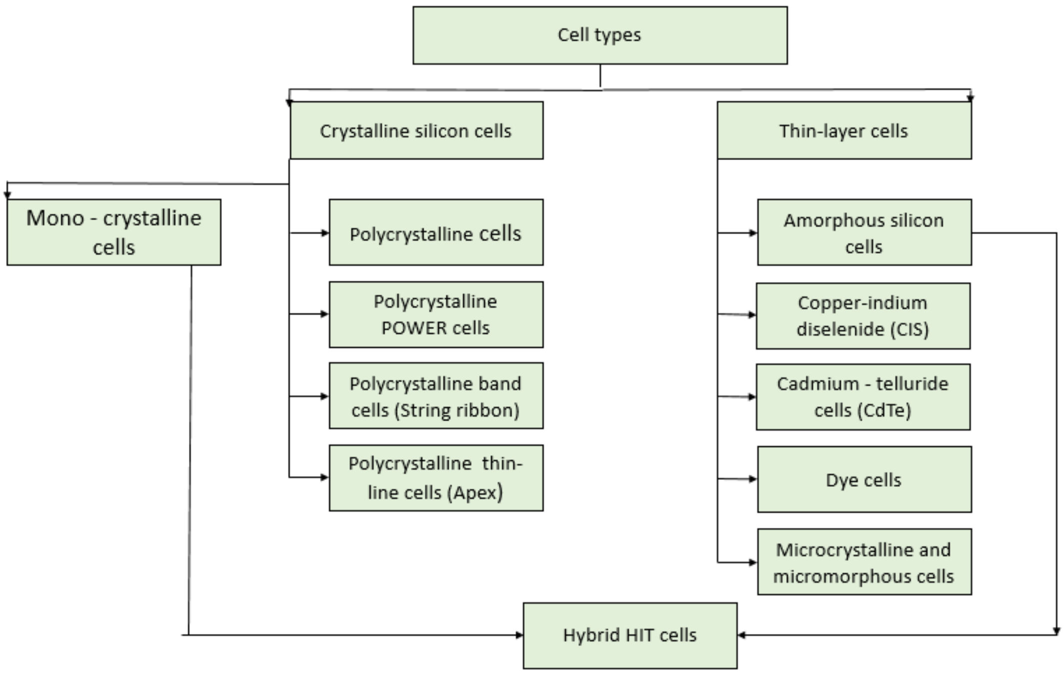

Figure 1.3 The main types of solar cells [16]

Generally, PV solar cells can be divided into three generations:

1. The **first generation** represents the solar cells that are constituted of crystalline silicon, which is the most used and commercialized material at the present moment. According to the usage of silicon in the solar cells manufacture process, the solar cells can be divided into two groups: mono – crystalline and polycrystalline with the efficiencies 15 – 18% and 13 – 16%, respectively. The primary limitation is an elevated production cost, which is dominated by the cost of the high purity silicon wafer [17]. The volume of production of the first generation solar cells is around 90% of the total production of the solar cells [18]. This market dominance will continue for the future, but there are economic challenges that must be overcome in order to maintain the growth of this technology, which confronts the competition with the "younger" generations.
2. The **second generation** of the PV solar cells was established with the objective to

reduce the production costs with more economical manufacture in terms of material and energy consumption, which uses thin – film solar cells, thus allowing to reduce the feedstock usage. The thickness of this film is 1 μm, compared to 200 μm in the first generation [18]. The advantage of this technology is a better exploitation of low sunlight radiation and diffuse radiation, however, the efficiency is lower (10-15%) [19].

3. The **third – generation** solar cells have emerged to improve the electrical performance of second generation thin – film cells, while keeping the production costs low. Commonly includes organic cells, nanostructures and polymers [18].

The front contacts of each solar cell are joined with the back contacts of the next cell. By connecting the negative pole (front) of each cell with the positive pole (back) of the following cell, the solar cells would be connected in series. The cells are spaced with the interval of a several millimetres between them. With the objective to protect the solar cells against mechanical stress, weathering and humidity, the cell strings are coupled in a transparent bonding material that also isolates the cells electrically [16].

For the connection of the solar systems to the grid, generally there are used the solar cells made from single – crystal and poly – crystal silicon. Although the polycrystalline silicon solar cells are less efficient, the production costs are lower. The amorphous silicon modules are mostly used in the small applications, camping and in the architecture. Currently the popularity of amorphous silicon solar cells is increasing and they are becoming established in the larger systems.

Electrically connected solar modules are combined by series and parallel connection to compose a larger unit – a PV generator, which produces electrical power, the amount of which is dependent on insolation and temperature. The series – connected modules are defined as a string. With the objective to prevent power loss in the whole system, only the same type of modules should be used. The number of series – connected modules defines the system voltage of the PV system, which matches to the input voltage of the connected inverter [16].

Shading

Shading is an important factor that must be taken into account when installing PV solar panels, since the shade produced by the panels should not be harmful to the following rows of the modules. Shading of photovoltaic modules is one of the most significant reasons of losses in a PV system. If there is one shaded module in the string, the whole string will perform less than expected. The shading of 10% of the area of a system can cause a loss of 50% in energy production [20]. Space requirements and shading losses can be minimized through optimization of the tilt angles and distances between the module rows. With the Formula 1.1 it is possible to calculate the optimal distance between the solar panel rows [16]:

$$d = \frac{b \times \sin(180° - \beta - \gamma)}{\sin\gamma} \tag{1.1}$$

Where d – Module row distance

b – Module width

β – Solar panel inclination angle

γ – Shading angle

PV arrays must be installed in a shade – free zones. However, grid – connected systems are typically found in urban and suburban areas and the modules are usually installed on roofs, where sometimes a shade is inevitable. It can significantly reduce the output of a PV array, so it should be avoided or minimized [16].

1.2.2 Photovoltaic module junction boxes, string diodes and fuses

The individual strings are associated together in the PV array junction box. The PV array junction box contains supply terminals and isolation points, and if is necessary, string fuses and string diodes. Surge arresters are often installed in PV conjunction boxes to direct the excess voltage to earth [16]. A junction box protects the electrical connections of the solar panel from environmental conditions [21]. In order to prevent humidity from entering the junction box, it is waterproofed and often sealed with silicon [22].

String diodes and fuses

With the objective to disconnect the individual module strings, string diodes can be placed in every string in series. Elevated currents can take place if there is a voltage drop in a string, caused for example by shading or by a short – circuit. If this happens, the parallel – connected string would operate like an external power source which would drive a fault current in the direction of consumption (reverse current) through the modules of the defective string. If the reverse current resistance of the modules is exceeded they will start to heat up, and the string diodes must be applied to prevent such reverse currents [22]. Without the string diodes, a reverse current would flow through the failed strings [16]. However, the majority of PV plants today are constructed without string diodes, since now the most modules have higher reverse current resistance and can easily resist a reverse current of 10 to 20 A [22].

With the objective to protect the solar module and string cables from the overloading, string fuses must be used in all unearthed cables. If string fuses are not used, the string conductors must be dimensioned to the maximum short – circuit current of the PV generator less the string current [16].

1.2.3 Grid – Connected Inverter

The solar inverter, also known as DC – AC inverter, is the connection unit between the PV array and the alternating current (AC) grid and AC loads. Its principal purpose is to convert the solar direct current (DC) electricity generated by the PV array into AC electricity and to adjust it to the frequency and voltage level of the electrical system. Using modern power electronics, the conversion to grid – standard alternating current occurs with very small losses [16].

The grid – connected inverters have the following targets:

- Conversion of the DC generated by the PV modules into main – standard AC
- Regulations of the inverter's operating point to the maximum power point (MPP) of the PV modules
- Recording of the operating data and signalling (data storage and transfer) [16]

In order to feed the maximum power into the electricity grid, the inverter should work in the MPP of the PV array. Since the module's voltage and current may vary significantly because of the weather conditions, the inverter needs to move its operating point with the objective to function optimally. So, the inverter's MPP tracker guarantees that the inverter is adjusted to the MPP point [16].

In grid – connected PV systems, the inverter is connected to the main electricity grid directly or through the building's grid. In case of direct connection, the produced electrical energy would be delivered directly into the grid. In case of coupling to the building's grid, the produced electricity would be first consumed in the building, and any excess would be delivered to the main electricity grid [16].

The choice of the inverter defines the system concept – central or decentralized. Thus, the connection of the PV modules for the strings formation and their parallel connection should be done in coordination with the inverter. The grid – connected inverters can be divided into the three main groups: the central inverters for the whole PV system; the string inverters for each string and the module inverters for each module. The main characteristics of these inverters [16]:

1. **Central inverters** are designed for PV systems with large arrays installed on buildings, industrial facilities as well as field installations – they represent fundamentally just a very large string inverter [23]. Central inverters are analogous to the string inverters but they are much bigger and can support more strings of the solar panels. Thus, the strings are not running directly to the inverter, as in case of string inverter, but the strings are connected together in a common combiner box that runs the DC power to the central inverter where it is converted to AC power [23].
    - In the concept with low voltage (LV) range, just a few solar modules are connected in series in a string. The advantage of such short strings, when compared to the longer strings, is that shadows have less influence since the module with the largest shading in a string defines the entire string current. However, the disadvantage is the resulting high currents. Relatively high cable sections have to be used to reduce the ohmic losses [16].
    - In the concept with higher voltage range, greater number of the solar modules are connected in series in a string. The advantage of this concept is that smaller cable cross sections can be applied because of the lower currents. However, the disadvantage is the greater shading losses due to the longer strings [16].
    - In Master – Slave concept, PV system uses a central inverter concept based on the master – slave principle. The main idea is the usage of the several central inverters (usually two to three). The total power is divided by the number of inverters. An inverter is a master device and operates in lower irradiance ranges. When the irradiance increases, the power limit of the master device is achieved so the next inverter (slave) must be connected. The advantage of this operating principle is that when the irradiance is low, just one inverter operates (master), so the efficiency is higher than in case of only one central inverter. However, the disadvantage of this concept is the higher investment costs compared with central inverters [16].
2. **String inverters** are used in the systems with outputs up to 3 kW. In the most cases, the whole PV array forms just one string. Medium – sized systems can have two or three strings connected to the inverter, resulting in a sub – array concept. An inverter is used per sub – array or per string. It must be guaranteed that solar modules with the same orientation and angle are connected together to form a string. The main advantages when using string inverters is the easier installation and reduced installation costs. However, in case of the long strings, the shading can result the greater power losses [16].

3. In the **Module inverter** concept there is a small box situated on the back of or very close to a solar panel which converts the DC electricity produced by a single solar panel into AC electricity [23]. They are becoming a popular choice for residential and commercial installations [24]. The main advantage of the module inverter is that it does not work in sequence, thus, if something goes wrong with one inverter, the other inverters would remain unaffected [25]. Moreover, if one or more solar panels are shaded or are performing on a lower level compared to the others, the performance of the remaining panels would not be influenced. This makes module inverters suitable for installations which face shading issues [25]. The disadvantage is that module inverters are still relatively expensive [16].

1.2.4 Direct and Alternating Current cabling

Photovoltaic system cables are single – conductor electrical wire and cable assemblies that connect different components in a PV system. These cables are flexible and are set for outdoor usage, meaning that they have to be waterproof, ultraviolet (UV) – resistant and be able to tolerate various temperature fluctuations because of its exposure to the sunlight [26].

Cables used for the connecting individual PV modules into a string to form a PV generator are called string cables, and all strings in parallel are connected to generator junction box [16]. The DC main cable connects the PV junction box with the inverter while AC connection cable links the inverter to the electricity grid through the protection equipment [16].

1.2.5 Direct Current load switch

When the fault occurs or when the maintenance works are needed to be carried out, it is must be possible to isolate the inverter from the PV generator. The DC load switch is used for this purpose. The DC main switch should have load switching capability and be set for the maximum open – circuit voltage of the solar generator and for the maximum generator current. The DC main switch is often placed in the generator junction box. The plug connectors may only work as isolators without load. When the irradiance is sufficient, the PV system delivers energy and therefore is under the load. If a plug connector would be detached under the load, the DC may result in a long burning arc, leading to the serious safety and fire risks [16].

1.3 Photovoltaic self – consumption in Portugal

The self – consumption of PV electricity is based on the concept that PV electrical energy would be first used for the local consumption and the excess would be delivered into the public energy grid [27]. The following Figure 1.4 represents the working mechanism of photovoltaic self – consumption system.

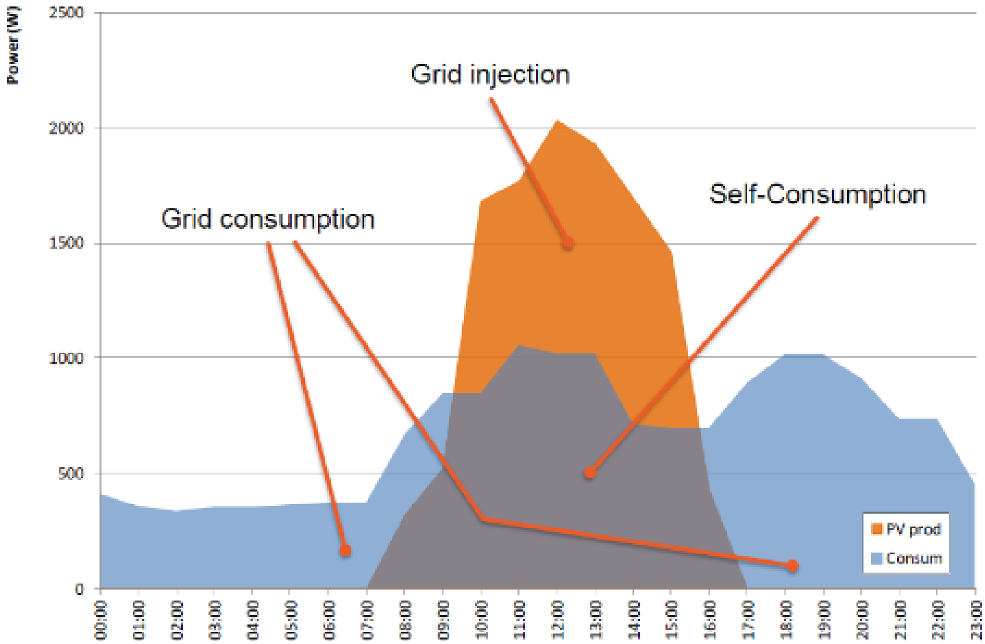

Figure 1.4 Working principle of the PV self – consumption [27]

According to this figure, the portion of the produced energy in the period from 7 am to 5 pm is locally consumed and the surplus is injected into the public grid (this injection should be minimized). During the evening hours, when the solar panel does not produce electricity, the required electrical energy is supplied by the public grid.

1.3.1 Legal framework

The technology development in combination with the reduction of the installations costs and advantageous feed – in tariff (FIT) regime have led to the essential oversizing of the installations with respect to the local consumption profile. This resulted in a significant amount of the produced energy injection into the public grid.

In October, 2014 there was published the Decree – Law No. 153/2014 that combined in a common legal framework several production regimes [28]. It had the objective to promote the small – scale installations that are duly sized in order to better fit to the consumption profile that exists at the installation site.

This Decree – Law introduced a new regime for small production units (UPPs) and self – consumption units (UPACs), replacing the remuneration regime that was previously applied to micro and small – scale generation units [28]. There are common regulations and certain particularities for UPACs and UPPs. UPPs can have an installed capacity of up to 250 kW whereas UPACs can have an installed capacity between 200 W and more than 1 MW . The main difference between them is that in case of UPPs 100% of electrical energy is injected into the public grid, whereas the electricity produced by UPACs is consumed at the point of installation and the excess of energy is injected into the public grid. The “prosumer” can request the issuance of Guarantees of Origin related to the electricity produced by UPAC and consumed from renewable energy sources [28].

The following rules are applicable to UPACs [28]:

- UPACs with an installed capacity exceeding 1 MW require the relevant licences for installation and operation
- UPACs with an installed capacity exceeding 200 W but no more than 1,5 kW, or which installation is not connected to the public energy grid, need only prior notification before starting operation. This notification should be addressed to the Directorate General for Energy and Geology (DGEG) through the electronic registration system
- UPACs with an installed capacity not exceeding 200 W are free from any form of prior control [29].

The general requirements for the PV self – consumption system in Portugal are following [29]:

Type of primary resource: all type of sources, renewable – based sources or not

Installed power limit: installed power must be less than the contracted power for the existing installation

Energy production requirements: annual energy production shall be less than local energy consumption; excess of energy locally produced is injected into the public grid

Remuneration scheme: energy injected in the public grid is remunerated at 90% of the market clearing price [30]

Metering: the meter is obligatory for the installed powers > 1,5 kW connected to the public grid. For the self – consumption measurement, three different meters are required: a PV meter for the produced solar energy, a feed – in meter and an electricity meter for the purchased energy.

The feed – in and electricity meters can be combined into a single bidirectional meter. Self – consumption, which is compensated separately, is based on the difference in the data collected by the PV meter and the feed – in meter. Thus, a feed – in meter measures the excess solar power that is not consumed directly, but delivered into the public grid [31]. The following Figure 1.5 depicts the distribution of installed power of UPACs in Portugal since 2015 until April 2016.

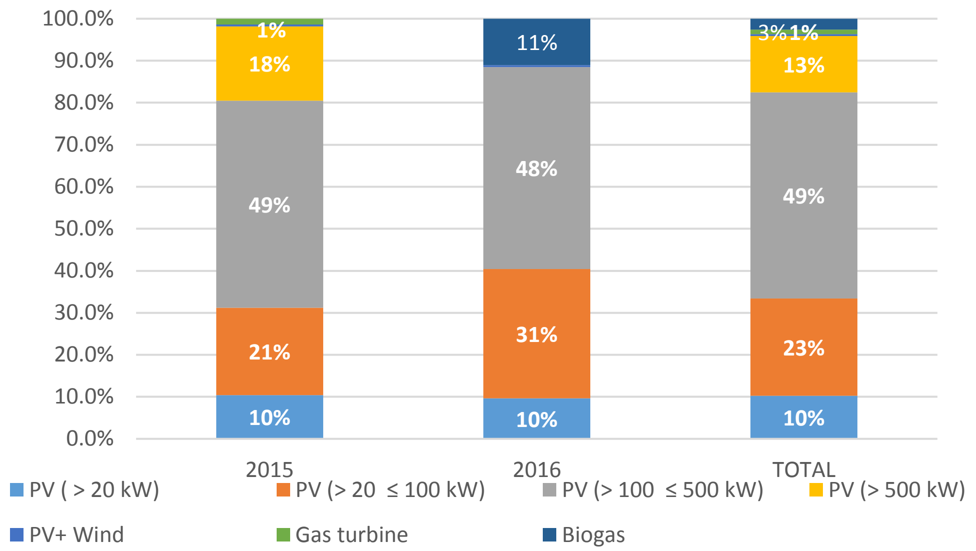

Figure 1.5 installed power distribution [32]

Up to April 2016, 588 units were registered corresponding to the total installed capacity of 29,9 MW [32]. The PV self – consumption systems with the installed capacity of 100 – 500 kW contribute to 49% of the total installed capacities of UPACs in Portugal.

1.3.2 Licensing and grid connection

The installation of UPACs is usually subject to the prior registration and operation certification. All the process is managed using an electronic platform. The producer must submit a request to the electronic registration system (SERUP). As soon as the production unit has been registered, the producer must install it using an authorised installation entity. When the installation is finished, the producer must submit a request for inspection of the production unit. If the inspection report concludes that the unit has no defects, the operation certificate would be issued and the production unit would be definitely registered [29].

SERUP is an electronic platform, accessible through an Internet portal which provides the following functionalities [29] :

Procedure for the registration obtaining

The procedure for registration the production units with an installed capacity exceeding 1,5kW starts with the formulation of the application in SERUP and concludes with its acceptance.

Procedure for obtaining a certificate of operation

The definitive operation certificate shall be issued to the registry holder after the installation of the production unit.

Procedure of the inspection

The holder of the accepted registry installs the production unit and requests to carry out the inspection of the production unit. The inspection shall be concluded with the issuance of the inspection report which shall conclude on the compliance of the production unit.

Re – inspection procedure

If the defects or nonconformities are detected during the inspection process, the holder of the production unit must correct them within the certain period of time, at the end of which he shall request the re – inspection of the UP.

Changes in the registry of the production unit

The alteration of the characteristics of the UP and of its registry needs a new registration, applicable to the whole installation [28].

1.3.3 Self – consumption remuneration

When the generated electricity is not fully self – consumed, one of the options to avoid its waste is the sale of the production surplus to the public electrical grid. This surplus will be remunerated according to the tariffs established by the Iberian Energy Market Operator (OMIE). The price of the electrical energy supplied into the grid is calculated according to the Formula 1.2 [28]:

$$\mathrm{R_{UPAC,m}} = \mathrm{E_{supplied,m}} \times \mathrm{OMIE_m} \times 0{,}9 \tag{1.2}$$

Where $R_{UPAC,m}$ – The remuneration for electricity supplied into the public grid in month "m", in euro

$E_{supplied,m}$ – The energy supplied n month “m”, in kWh

$OMIE_m$ – The price resulting from the simple arithmetic mean of the closing prices of the OMIE for Portugal (daily market), for month “m”, in €/kWh

m – The month to which is referred the electricity supplied into the grid

The following Figure 1.6 represents the market prices for the electrical energy in Portugal during 2015 – 2016. As it is possible to see, the electricity price varies significantly during the year, whereas in Spring, the price is the lowest [33]. It is explained by the increased hydropower generation which represents low marginal costs, resulting in lower electricity price formation.

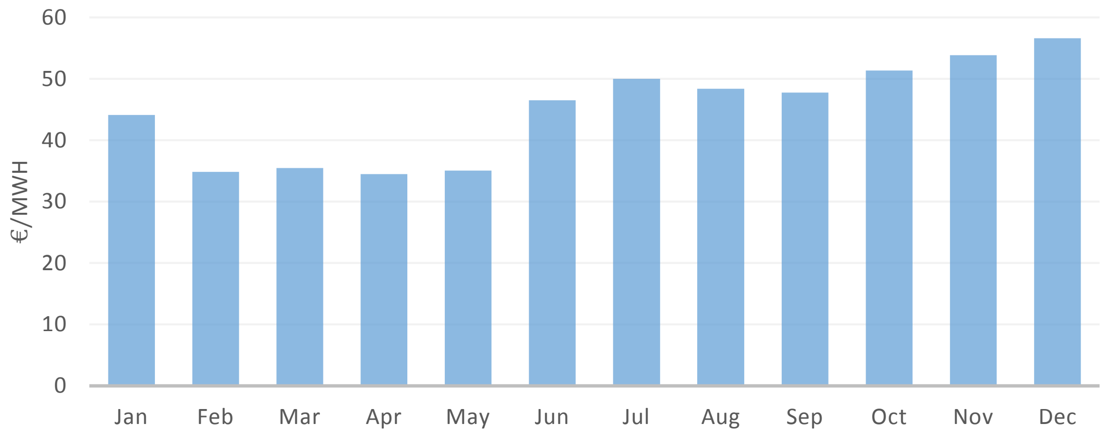

Figure 1.6 The average electricity market price in Portugal in 2015 – 2016 (Source: REN)

Using the data provided by the Portuguese Transmission System Operator (TSO) *REN* concerning the hourly electricity market prices and hourly electricity generation by the solar panels and wind turbines, it is possible to conclude that the price of the electricity generated by solar panels is slightly higher than by the wind turbines. The data is presented in the following Figure 1.7:

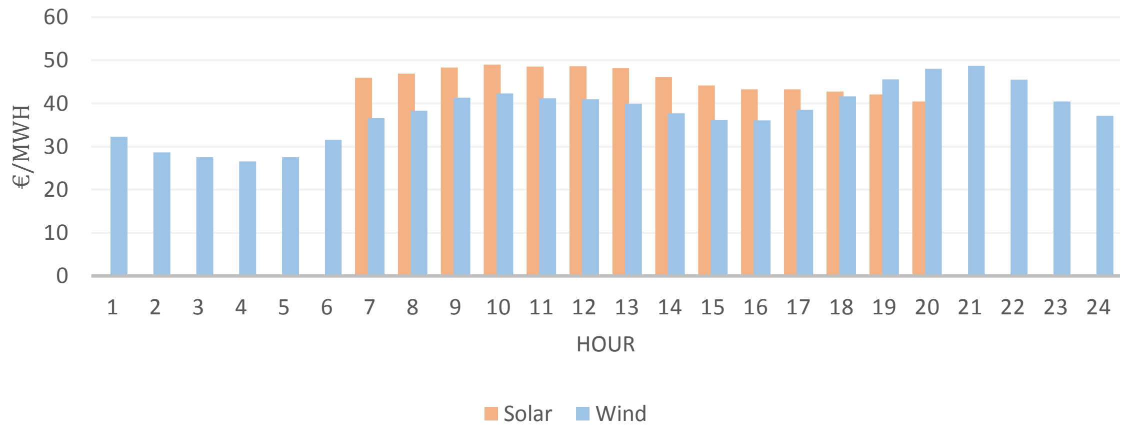

Figure 1.7 The comparison of the solar and wind electricity price (Source: REN)

However, there is little willingness to invest in self – production because of the financial risks associated to it. Low and fluctuating wholesale prices, reduced by 10%, do not provide sufficient investment security for self – production. For example, in 2015 the average monthly wholesale market price was around 38 €/MWh, of which 10% are deducted as a contribution for grid maintenance. Compared to the previous FIT scheme, the amortization period would be significantly longer if the prosumer wants to export the excess electricity to the public grid. For example, the reference FIT for mini – production units (was phased out by end of 2014) was 106 €/MWh for solar PV [30].

1.3.4 Globally existing valuing self – consumption approaches

The prosumers, generating renewable energy may still need to deliver the non – consumed electricity into the public energy grid and gain a certain value for it. The following approaches are applied with the objective to estimate the value of the energy injected into the grid [7]:

- **Self – consumption and FIT/premium approach**. The prosumer receives support for non – consumed electricity that is supplied into the public grid. With the objective to motivate the consumers to increase their direct consumption of self – generated electricity instead of injecting it into the public grid, only electricity self – consumed above a given rate (e.g. 30%) can receive a premium tariff. This model was implemented in 2009 – 2012 in Germany, however, the fast reduction in PV generation costs has resulted in elimination of this premium tariff by German authorities [7].
- **Net metering approach**. Under this approach, the excess electricity injected into the public grid can be used at a later time to compensate consumption during the time periods when the local renewable production is absent or not sufficient. As a result, the prosumers use the energy grid as a reserve system for their surplus power production. Usually, net metering approaches have limited system size to which it is applicable, with limits between 20 kW to 2 MW. The applicable billing period can be prolonged from one hour over long periods of time [7]. This remuneration scheme is applied for instance in Belgium, Denmark etc. [27]. Outside the EU, net metering forms the basis of support for the PV across USA and Australian states. From the consumer point of view, net energy metering is easier to apply and to understand, because it based on the use of a single meter. Under this approach, consumers with self – production are using the public grid to artificially store electricity produced at one period of time to consume it at another period of time [7].

- **Self – consumption and market valuing approach**. The electricity that is not self – consumed but is supplied into the public grid would be remunerated at a market price. If to offer a lower tariff for electricity delivery into the energy grid during certain periods of the day, the prosumers would be motivated to consume more of their electricity. From a policy perspective, this remuneration mechanism may be the most sustainable. From a consumer perspective, it can also be attractive, especially for commercial and industrial customers that can reach high self – consumption levels. For example under the Portuguese self – consumption regulation, electricity delivered into the public energy grid is remunerated at 90% of an average Iberian spot price [7].

2. Green energy trade mechanisms

Nowadays more and more energy consumers are willing to buy the energy generated from renewable energy sources. It is possible to purchase environmental benefit and physical electricity separately. The environmental benefit of renewable electricity generation can be represented by certificates. These certificates are known as Renewable Energy Certificates (RECs) which represent the environmental attributes of the renewable energy. Each REC corresponds to 1 MWh. The buyers can select RECs based on the energy resource such as wind, solar, geothermal etc. RECs were widely implemented in Europe before the introduction of the Guarantees of Origin (GOs) in 2001 and after the RECs were consequently phased out in the most European countries. The price of RECs and GOs is established by the market and is influenced by factors such as the time of energy production and energy source [34].

2.1 Recognition of the Guarantees of Origin

This thesis focuses especially on the GOs system, since it is implemented both in Estonia and Portugal. Guarantee of Origin is an electronic document which is issued to a producer on the basis of his application. The standard unit of one GO is 1 MWh [35]. The tracking system of GOs is instrumental to the reliable authentication of claims about the origin of a certain quantity of final energy. The objective of this policy is to permit power suppliers to show in an uniform way that their energy was generated from RES [9].

According to the EU Directive 2009/28/EC, Article 15, section 2: "*The guarantee of origin shall have no function in terms of a Member States compliance with Article 3"*. Article 3 describes the "*Mandatory national overall targets and measures for the use of energy from renewable sources*" [36]. This is one of the peculiarities of the system that imported energy is renewable, but it does not contribute to the national targets achievement under EU law. Thus, GO system forms a market disconnected from the physical trading of electricity, achieved through digital accounts held by suppliers of renewable electricity and GO traders [37].

The life cycle of each GO has three phases: issuance, transfer and cancellation. The following Figure 2.1 depicts in which way a Guarantee of Origin is moved between these three phases [38].

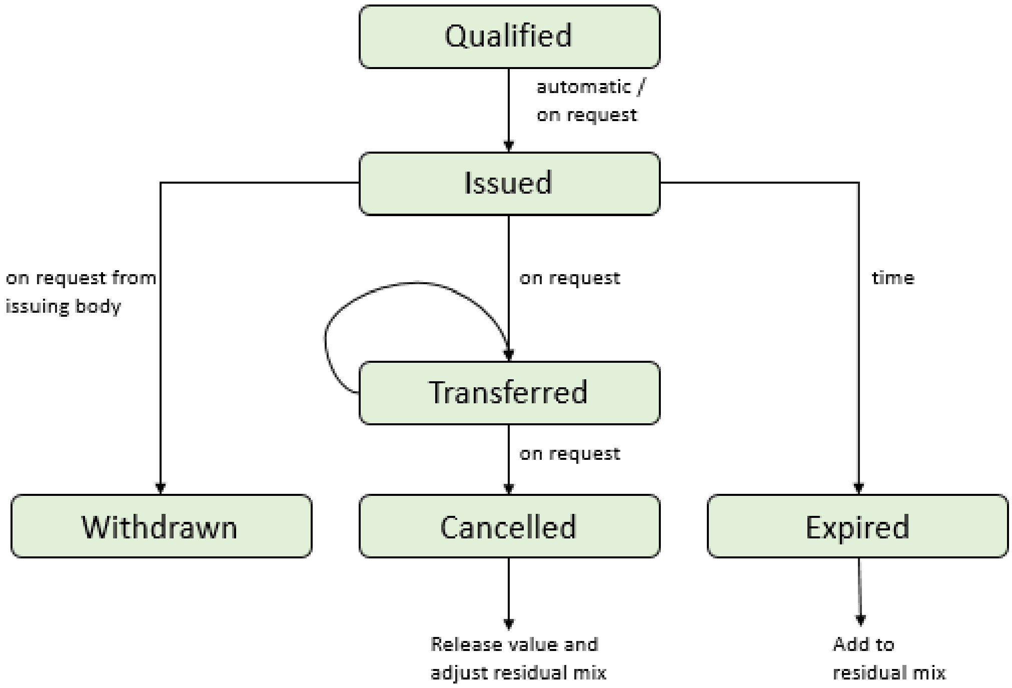

Figure 2.1 Life Cycle of the Guarantee of Origin [38]

- The GOs are issued on registries operated by Association of Issuing Bodies (AIB) Members for the output of plants registered in connection with national legislation
- The GOs may be transferred from the producer's account to the accounts of other traders and energy suppliers, either within country of origin or to the other registries operated by AIB Members across Europe
- Cancellation refers to the removal of the GOs from circulation. This happens when the value of the certificate is realised
- The certificate can be withdrawn in case if it has been issued by mistake. Moreover, it can be expired, meaning that a certificate has not been cancelled by a deadline [38]

When applying for GOs, the amount requested is automatically compared to the measuring data in the Data Warehouse, and the applicant can only request issuance of GOs for electricity generated in the last 12 months, since the validity of a GO ends 12 months after the generation of the corresponding unit of energy [38].

The procedures necessary for registration of the Production Device is described in the following Figure 2.2:

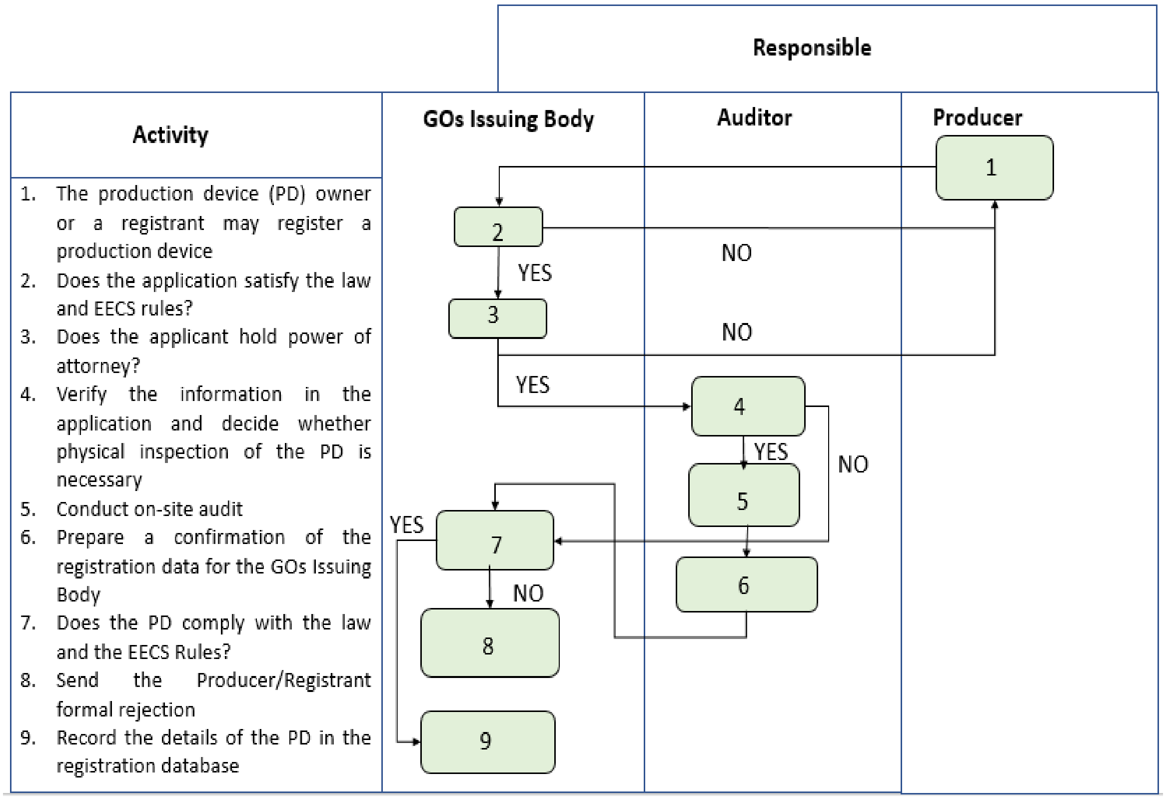

Figure 2.2 Procedures for the registration of the Production Device [39] [40]

The Figure 2.3 represents the conditions for the issuance of the GOs for the produced electrical energy.

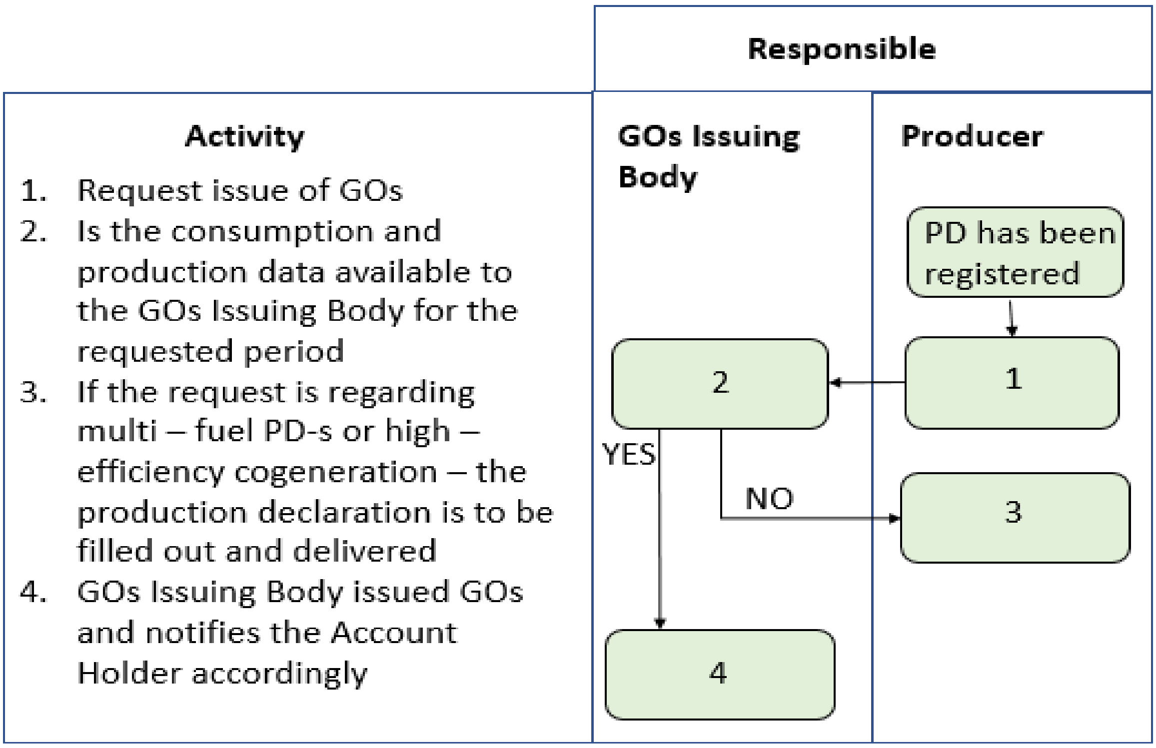

Figure 2.3 The procedures for the GOs issuance [39]

It is important to distinguish a difference between the GOs and Tradable Green Certificates (TGCs) that are employed for the support schemes [41]. For example, in Sweden a GOs and TGCs can be bought for the same MWh generated electricity since it is allowed by the Renewable Energy Directive and legislation in Sweden. However, there is a big difference in GOs and TGCs functions. The GOs may be voluntarily bought in a market by any customer with the objective to claim the related attributes of the electricity, improving the Electricity Disclosure. Meanwhile TGCs have to be mandatory bought by the electricity customers (the share of the bought TGCs relates to the total electricity consumption and is defined by the quota levels) with the objective to enable the growth of the renewable electricity production [41].

2.1.1 Europe

In Europe, there have been existing the RECs and GO systems which enabled the certificates to be traded in an open international market [42]. RECs aimed to encourage the electricity production from RES and to guarantee to the consumer that by acquiring RECs, there is a promotion of the renewable energy and the reduction in the consumption of fossil fuels and harmful gases emission to the atmosphere.

However, in 2012 RECS declared that a standardized GO, for all of Europe will be the only reliable tracking system. That means that RECs system no longer exists in Europe, it was a voluntary scheme that pre – dated internationally recognized and highly reliable GOs, and it was stopped in December 2015. RECs were identical to GOs, except that they had no status in law [43].

The GO concept is coming from the Renewable Electricity Directive 2001/77/EC, which mandated all Member States to elaborate a reliable scheme for GOs [44]. The consequent modifications concerning the GOs were introduced by European Directive 2009/28/EC. This Directive obliged Member States to give producers the opportunity to receive an electronic GO for electricity produced from RES. In addition to this, Member States may also offer GOs for heating and cooling systems [45].

According to the Directive 2009/72/EC of the European Parliament and Council concerning the rules for the internal electricity market, the member states must guarantee that electricity suppliers specify in or with the bills and in promotional materials made available to final customers the contribution of each energy source to the overall fuel mix of the supplier over the previous year in a clearly comparable way [10]. The energy produced from renewable sources must be proven by the GOs. The purpose of the Electricity Disclosure is to give the relevant information to the consumers concerning the power production and to influence their choice, in order that the selection of the energy supplier would be not based just on electricity price. Meanwhile, the regulatory authority must guarantee that the information provided by supplier to their customers is trustable [41]. Electricity Disclosure is a powerful instrument, that allows the consultation with the public using the market forces and giving an opportunity for the European citizens to decide how their electricity is generated. The willingness to pay additionally for the green electricity is important for Electricity Disclosure, since the customers are given a chance of paying extra money for green electricity with the objective to improve their disclosure [41].

For a customer who purchases electricity without any special requirements, the electricity would be obtained through electricity exchange. The disclosed electricity will represent a mix of electricity produced from different energy sources. It is known as Residual Mix and it represents the consumption mix for all the customers who do not buy GOs [41]. As long as not all electricity consumption is clearly tracked to certain generation attributes, clear tracking mechanisms always need the support of the disclosure system, a residual mix, with the objective to prevent double counting [46].

For the Residual Mix calculation, it is necessary to consider the trading of GOs, as well as national and international statistics for electricity production, adjusted in respect with import and export figures. The related attributes for the electricity that have been proven by GOs must be excluded from the calculation of the Residual Mix with the objective to prevent double counting, a situation when the attributes from the same amount of produced electricity are claimed more than once [41]. For example, if the untracked consumption would be disclosed with the production mix (including attributes represented by GO), it would mean that the renewable attributes, which are clearly tracked, were double counted in electricity disclosure. That means, clearly tracked attributes must be removed from the energy source mix of other consumption (untracked consumption). If all electricity consumption was clearly tracked to specific generation attributes, the Residual Mix calculation would not be needed [47].

The organisation which deals with the Guarantees of Origins, AIB, contains 23 European countries, including Norway and Switzerland that have signed onto a standardized system of GO: the European Energy Certificate System (EECS) [48]. EECS is based on the coordinated structures and procedures, including a standard format for the interfere between national registries, contributing the international trade with standardized GO without the danger of double counting and double selling [9]. The GOs system has been developed by RECs system and AIB. AIB is a leading enabler of international transfer of the GOs [38]. The members of AIB first started operation in 2001. Since then, over 1 billion certificates have been created, and 80% of these have been used. The cancellation volume in 2010 reached around 200 TWh, accounting for about 35% of the renewable electricity production in Europe [41]. The Table 2.1 shows the list of AIB member countries, total installed capacity and technology from which the GOs are issued. For now, remaining non – EECS Member States are Bulgaria, Greece, Hungary, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia, and the UK [37].

Table 2.1 List of AIB members with the total installed capacity and technology eligible to GOs [39]

Country	Name of the company	Member of AIB	Total capacity installed (MW)	Technology
Austria	Energie-Control Austria	2001	20 070	PV, Hydro, Onshore wind
Belgium (Brussels)	BRUGEL	2008	51	Municipal Waste Incineration
Belgium (Flanders)	VREG	2006	3 539 836	Biogas, Biomass, Hydro, Onshore wind, PV
Belgium (Wallonia)	CWAPE	2007	1 162,4	Biomass, Onshore wind, Hydro, Solar
Belgium (Federal)	CREG	2015	706,6	Offshore wind
Croatia	HROTE	2014	42,2	Hydro
Cyprus	TSO-Cy	2014	157	Onshore wind
Czech Republic	OTE, a.s	2013	2 180	Wind, Solar, Thermal, Hydro
Denmark	Energinet.dk	2002	6 950	Biomass, Biogas, Onshore wind, Hydro, CHP, Solar
Estonia	Elering AS	2014	599,1	Onshore wind, Hydro, Biomass, Biogas
Finland	Finextra OY	2015	7 439	Onshore wind, Hydro, Solar, thermal
France	Powernext SA	2013	6 938	Hydro, biomass
Germany	German Environment Agency	2015	13 886,3	Onshore wind, Solar, Hydro, Biogas, Solid renewable fuels
Iceland	Landsnet hf.	2011	2 610,4	Hydro, Geothermal
Ireland	SEMO	2015	885,1	Hydro, Thermal, Onshore wind
Italy	GSE S.p.A.	2001	23 770	Onshore wind, Geothermal, Hydro, Solar, Thermoelectric
Luxembourg	ILR	2010	57,3	PV, Wind, Hydro, Municipal Waste
The Netherlands	CertiQ B.V.	2001	9 639	Biomass, Hydro, Solar, Onshore wind

Norway	Statnett SF	2002	32 446	Hydro, Onshore wind, Thermal
Slovenia	Agencija za energijo	2004		
Sweden	Grexel Systems Ltd.	2006	23 400	Onshore and offshore wind, Hydro, Thermal, Nuclear
Switzerland	Swissgrid AG	2002	20 773	Biomass, Hydro, Solar, Wind, Nuclear Natural Gas, Waste, Crude oil

GOs cover around 30% of all renewable electricity produced in the Europe. For more than two thirds of European renewable electricity production, there are no GOs issued. So, GOs system does not yet fully function as an unique tracking tool for renewable electricity [30].

The following Figure 2.4 depicts the contribution of each European country in the issuance of the GOs in 2015 [49].

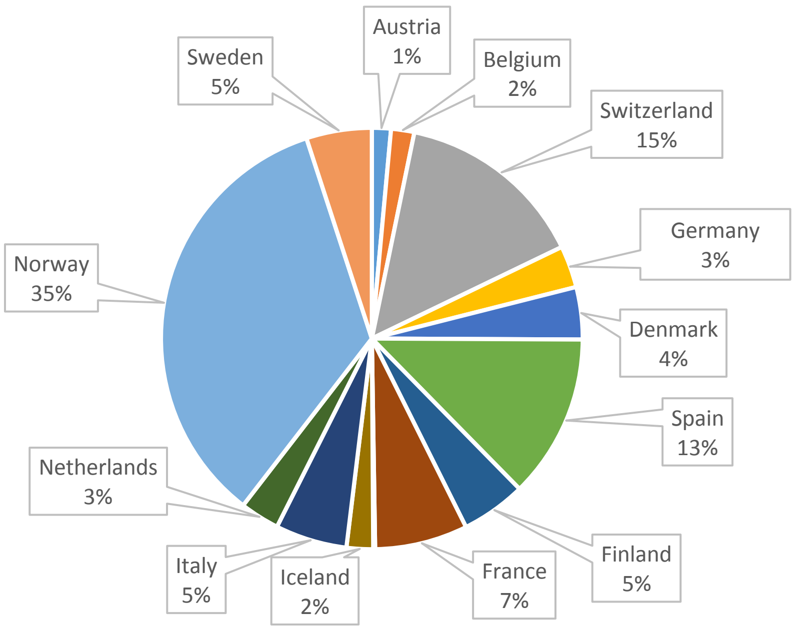

Figure 2.4 The issuance of the GOs in 2015 in Europe by country (Source: AIB)

As it is possible to see, the leaders in the GOs issuance are Norway with 35% of all the issued GOs in Europe, on the second place is Switzerland with its 15% and Spain with 13%. With the objective to demonstrate the difference between the leading countries in the issuance and the cancellation of GOs, the Figure 2.5 demonstrate the contribution of the European countries in the GOs cancellation [49].

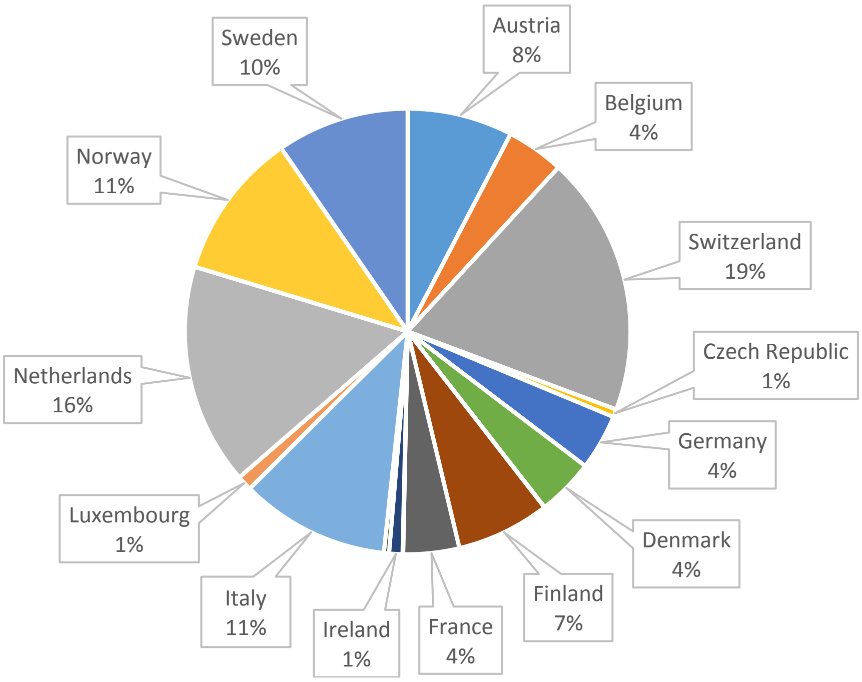

Figure 2.5 The cancellation of the GOs in 2015 in Europe by country (Source: AIB)

According to this figure, Norway represents just 11% of the cancelled GOs whereas the leaders in the cancellation of GOs is Switzerland and the Netherlands with 19% and 16% respectively.

The Figure 2.6 demonstrates the increasing volumes of the GOs issued in Europe for the solar energy 2009 – 2016 [49].

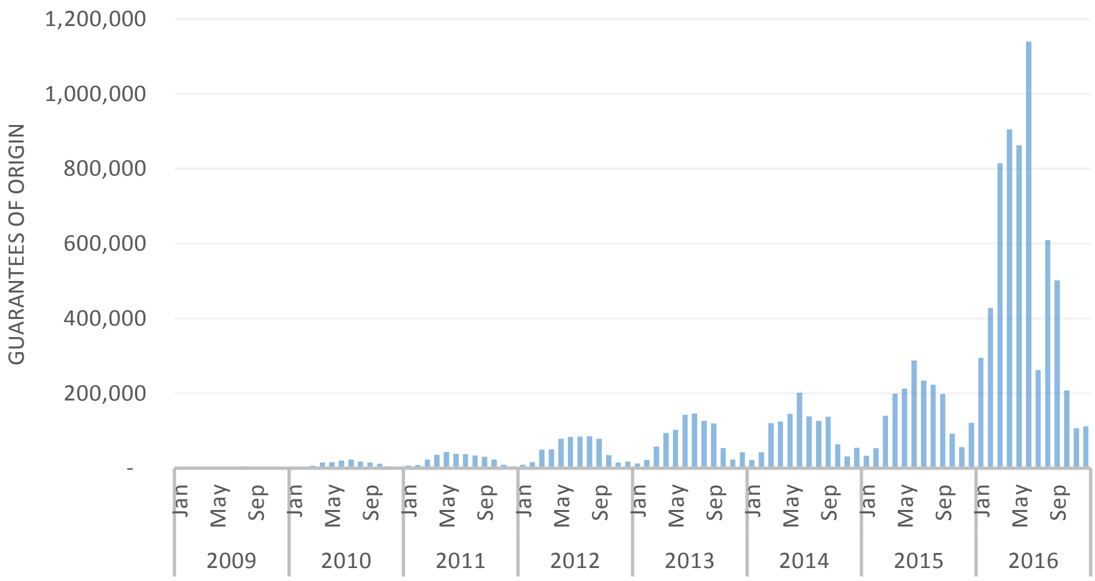

Figure 2.6 The issuance of GOs for solar energy 2009-2016 (Source: AIB)

It is possible to conclude that the GOs issuance for solar energy is constantly growing and the maximum issuance corresponds to the summer months when the solar radiation reaches its maximum levels. According to the AIB activity statistics, in 2016 Spain was the leader in the issuance of the GOs for the solar energy accounting for the issuance of 4 349 469 GOs. On the second place was Switzerland with 1 010 582 issued GOs [49].

GOs can only be issued to the owners of plants that have been registered for an EECS Scheme which implied the formal application. The plant owner is obliged to give the information about itself and the plant, including the suitable technology and possible energy sources, commissioning dates and capacities and details concerning the public support received. Registration requires the plant to be coordinated with legal requirements and the requirements of the relevant EECS Scheme as set out in the Domain Scheme. When the plant has been registered, it is possible to request the issuance of GOs [38]. The following Figure 2.7 represents the distribution of the cancelled GOs in Europe in accordance with the technology type [49].

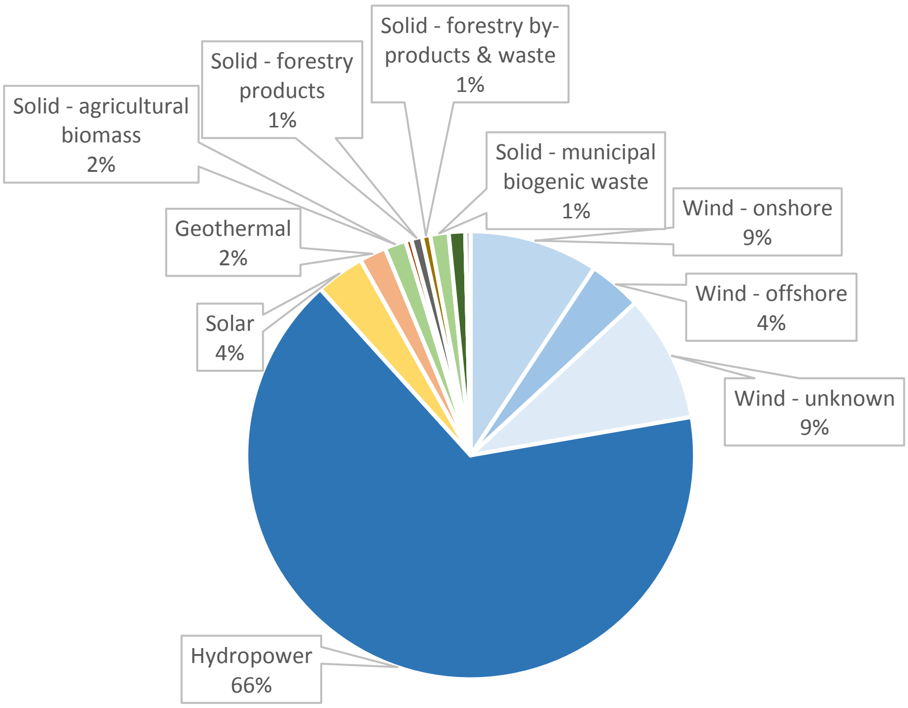

Figure 2.7 The GOs cancellation in 2016 by the technology type (Source: AIB)

It is possible to conclude, that the most popular technology type for the GOs cancellations is a hydropower plant. Nevertheless, the AIB activity statistics reveals that in 2015 77% of all the cancelled GOs originated from the hydropower. However, according to the figure presented above, the share of the cancelled GOs from hydropower decreased, accounting in 2016 for the 66% of the total cancelled GOs, whereas the cancellation of GOs originating from other energy sources increased [49].

2.1.2 Estonia

In accordance with the §58[1] Estonian Electricity Market Act (EMA), the Estonian TSO *Elering AS* issues GOs to the electricity producer, which prove that the electricity has been generated from RES or in an efficient combined heat and power (CHP) mode. The origin of the electricity consumed is verified by using GOs issued in Estonia or in another member state of the EU [50].

According to EMA §75[1] Power electricity supplier shall provide to the consumers the following information with a bill or with promotional materials [51]:

- The contribution of the electrical energy bought from the electricity market during the financial year prior to the selling period
- A reference to the website where there is presented information on the environmental impact in terms of CO_2 and SO_2 emissions, deposited oil shale ash and radioactive waste created upon electricity generation during the financial year prior to selling period
- The share of electricity supplied to the consumers that is disclosed by GOs
- The share of electricity which was not disclosed by GOs, the residual mix published by the Transmission System Operator (TSO) must be used

In September 2014 *Elering AS* became a member of AIB. The following Figure 2.8 represents the issuance, imports and exports of the GOs since September 2014 until September 2016 [49].

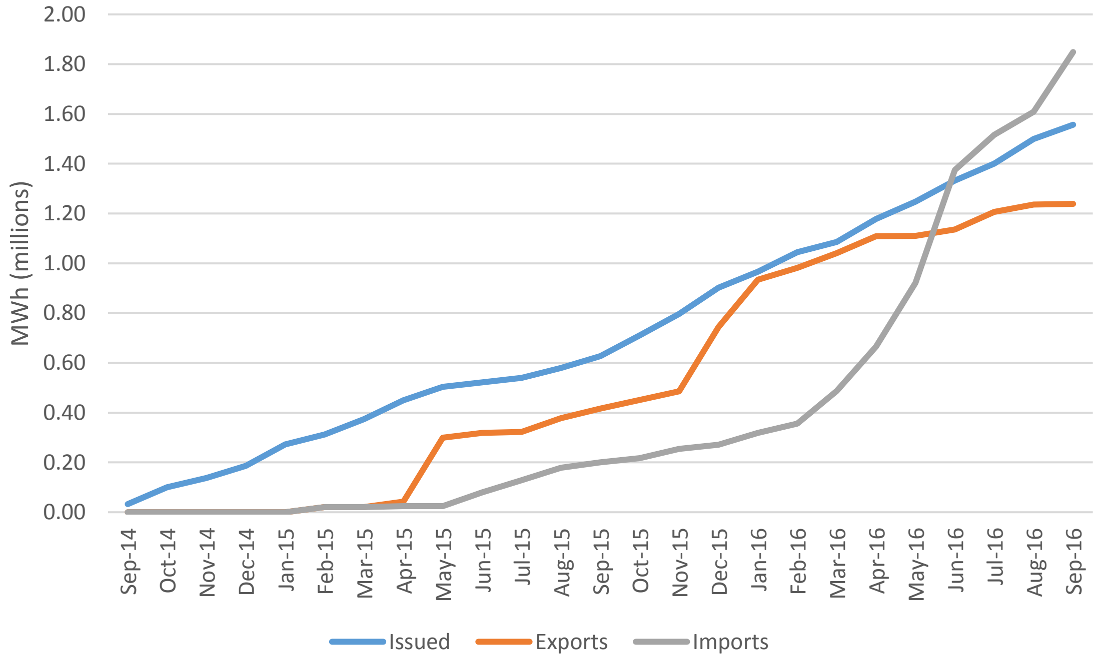

Figure 2.8 The amount of issued, exported and imported GOs in Estonia (Source: AIB)

The Terms and Conditions for the GOs issuance [50]:

- A producer located in the Republic of Estonia or a trader authorized by such producer has the right to submit an application for the issuance of a GO for electricity generated from RES and in an efficient CHP mode
- Each GO is issued in respect to each MWh of electricity produced
- When applying for GOs for electricity generated in an efficient CHP mode, it is necessary to provide to the TSO the relevant information concerning the checking the implementation of efficiency requirements
- For the GOs trading, the market participant is not required to be located in the Estonia, but it does need to register as a trader in the database and fill out a form provided by the TSO. Producers as well as traders need to accept and sign the „Standard Terms and Conditions" to be able to use the GO database

According to *Elering AS*, currently in the Estonian GO database there are registered 36 market participants (including both producers and traders). The database has registered 34 generation units with a total capacity 599 MW. The Table 2.2 illustrates the types of technologies, generation unit number and the installed capacities [50].

Table 2.2 Registered generation units and the capacities per technology (Source: Elering AS)

Type of technology	Generation units number	Installed capacity (MW)
Wind	16	283,7
Hydro power	7	4,114
Biogas	5	3,66
Biomass	6	307,6

In 2015, from RES in Estonia there were produced 1 507 GWh of electricity, and were issued 1 221 GWh GOs [50].

It is important to mention that in Estonia the EECS scheme allows the other types of the renewable energy support (investment support, production support) [40]. Thus, in addition to the revenues from the sale of the electricity and renewable energy subsidies, GOs represent the potential source of revenues [52].

2.1.3 Portugal

In 2010 there were established two entities to act as Issuing Bodies for GOs (EEGO): with the implementation of the Decree – Law No. 23/2010 the Portuguese TSO *REN* was established as a EEGO for the issuance of the GOs from CHP and the Decree – Law No. 141/2010 established National Laboratory for Energy and Geology (NLEG) as a EEGO for the GOs issuance from renewable energy sources [34].

The GOs issued in other Member States are recognised by the Portuguese state. The producers of energy from renewable sources should request EEGO for the issuance of the GOs with respect to the energy they generated. However, compared to Estonia, the issuance of the GOs cannot be cumulative with any other mechanisms of support for the energy production from RES. Under the support mechanisms there is considered any type of the support which promotes the energy production from RES resulting in a reduction of the energy cost: investment support, tax exemption or reduction and direct price – based support mechanisms, such as FIT [53].

The GO shall specify the following information:

- Whether the GO is related to electricity or heating or cooling
- The source from which the energy was produced and the start and end date of production
- The identification, location, type and capacity of the facility where the energy was produced
- Whether the installation benefited from investment support or benefited in any way from a national support scheme and specify the type of this support scheme
- The date of entry into service of the installation
- The date and the country of the issuance and a unique identification number [53]

During the last four years, there were introduced two important changes concerning the issuance of the GOs in Portugal in 2013 and in 2015:

Decree – Law No. 39/2013 granted *REN* the competencies of EEGO for the energy production from renewable sources. So, according to this Decree – Law, *REN* performed the tasks of EEGO both for the energy production from CHP and renewable sources, more specifically [54]:

- Implementation and administration of a system of GOs issuance for electricity and power for heating and cooling produced from RES, which includes the electronic registration, issuance, transfer and cancellation of the respective documents

- Auditing and inspection of facilities for the production of energy from renewable sources, and an inspection of energy metering equipment which guarantees the correct qualification of the facilities
- Provision of the appropriate information concerning the issuance of the GOs, for public consultation, namely on a website [54]

However, *REN* never started the activity as EEGO in the framework of this Decree – Law, since it was expecting for the Manual of Procedures to be approved. *REN* has been a member of the AIB since 2003 [39]. The following Figure 2.9 depicts the issuance of the GOs in the period of 2005 – 2014. According to the AIB Annual Report 2015 by the July 2014 in Portugal were issued 1 455 576 GOs [49].

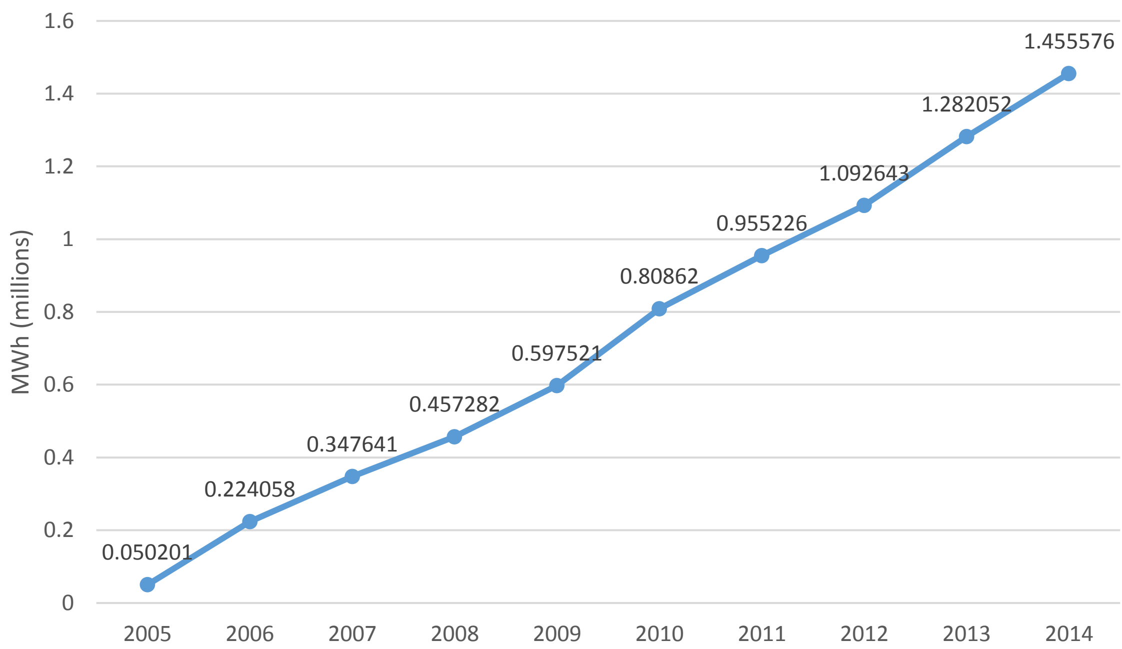

Figure 2.9 The amount of the issued GOs in Portugal 2005-2014 (Source: AIB)

According to the AIB Annual Report 2015, the technology type that benefited from GOs was hydro with the 4 production devices and the total installed capacity of 68 MW [39].

The Decree – Law No. 68-A/2015 placed EEGO to the Directorate – General for Energy and Geology (DGEG) both for the issuance of GOs from RES and from efficient cogeneration mode [55]. Additionally, at the end of 2015 *REN* stopped to be a member of the AIB [56].

In the present thesis, there were studied the ways of the transfer of the renewable energy attributes from Portugal, using the PV system for self – consumption. One of the main doubts is whether the GOs can be issued just for the energy injected into the energy grid or also self –

consumed energy. The following Table 2.3 shows for which type of energy some of the AIB countries issue the GOs:

Table 2.3 Type of the energy for which the GOs are issued in some of the AIB member countries

Country	Issuance of Guarantees of Origin
Belgium (Brussels)	Net electricity production
Denmark	Net electricity production
Sweden	Gross electricity production
Italy	Net electricity production
Ireland	Net electricity production
Netherlands	Gross electricity production (Electricity injected into the grid + consumed onsite. Electricity consumed onsite cannot be traded or cancelled, they only exist as a support to be paid a producer
Slovenia	Net electricity production
Luxembourg	Net electricity production
Finland	Net electricity production
Estonia	Net electricity production
Portugal	Gross electricity production

Net electricity production refers to the issuance of the GOs for the electricity which was injected into the grid. That means brutto electricity minus auxiliary devices or power plant own consumption. Gross electricity production refers to the total gross electricity generation including self – consumption. As it is possible to see from this table, the majority of the countries issue GOs just for the electricity injected into the grid. However, for example in the Netherlands, the GOs are issued both for the electricity injected into the grid and the electricity consumed onsite. However, the GOs issued from the electricity self – consumption cannot be traded or cancelled.

The Portuguese GO system is still under development. However, according to the Decree – Law No. 153/2014 article 7, all the producers of electricity from RES can receive GOs, including those who produced energy for self – consumption [28]. However, there are still no approved rules if the issued GOs for the energy self – consumed can be transferred between the

AIB member states. Currently Portugal is an observer of the AIB system, which usually means that sooner or later it will become its member. However, there is still no approved legislation, either internally for Portugal or for the future AIB "Domain Protocol".

2.2 The transfer of the Guarantees of Origin from Portugal to Estonia

After the GOs issuance to the producer account in an electronic certificate registry, its owner can transfer it to another account holder. The GOs issuing entity records the transfer of ownership in the registry, files any documentation concerning the transaction [57]. It is important to mention, that the GOs can be directly transferred within the countries which are the members of AIB. Currently, the GOs transfer from the Portuguese to Estonian registries is complicated, since the Portuguese competent body, *REN* resigned from AIB on 31 of December 2015 and now AIB is in discussion with its successor DGEG [58]. The Estonian electronic database for GOs is connected with the AIB Hub's central registry, which permits the market participants to export and import GOs between registries managed by the competent authorities of other Member States [59].

If Portugal would be a member of AIB, it would be possible to register as a producer in the Portuguese registry (DGEG), in order to request the GOs issuance and transfer them to Estonia, and also register as a trader in Estonian registry (*Elering AS*) with the objective to import the Portuguese GOs and sell them in Estonia. However, currently it is not possible, so the only way of the Portuguese GOs cancellation in Estonia is possible through the mechanism called Ex-domain cancellations.

2.2.1 Production unit registration in Portugal and the GOs issuance

Currently the legislation concerning the GOs in Portugal is not clear. As it was mentioned above, Portuguese EEGO, *REN*, resigned AIB in the end of 2015 and now AIB is in discussion with DGEG, which is entitled to hold the role of EEGO. However, with the objective to have a basic idea which aspects are necessary to consider for the registration of the production device in Portugal, there was used the EECS Domain Protocol for Portugal published in 2012 for *REN*, which currently is not valid any more. According to this document, *REN* is a competent authority which controls the issuance, transfer and cancellation of certificates in Portugal. This Domain protocol set out the procedures, rights and obligations applicable to the Domain of Portugal and related to the EECS Electricity Scheme [60].

Registration of participants: Any legal person can be an EECS Participant and become an Account holder in the registry. To do this, the EECS Participant must sign the Standard Term and Conditions with *REN*, after which it will issue each authorized user with an identification and password to enable secure communications. The Account holder can keep the certificates in an account within the EECS Registration Database for Portugal. Moreover, the Account holder can make transfers of certificates to another Account in the same EECS Registration Database or to another EECS Registration Database [60].

Registration of a Production Device: The owner of a production device can register a production device located in Portugal in the EECS registration Database. The Registrant must give to *REN* the document stating that it fulfills the requirements of the EECS Schemes. An applicant registering a Production Device must provide a registration form which authorizes *REN* to copy all the items listed in the form to the EECS Registration Database. The Registrant must guarantee that the information given to *REN* is complete and accurate. On successful completion of the registration process, *REN* will assign an unique identifier to each registered Production Device [60].

2.2.2 Guarantees of Origin transfer from the Portuguese registry to Estonia

The implementation of the GOs in all European countries should be based on the EECS which is operated by AIB. According to the EECS Rules, the cancellation of the GOs for disclosure of electricity which is consumed in another domain, is not possible. However, there are exceptions from this rule that can be made for a limited time in case if it is technically impossible to transfer GOs into the domain where a consumer is located [61]. In these exceptions there are used Ex – domain cancellations of GOs, where a GO is cancelled in one registry and a proof of cancellation can be transferred to another country in order to be used there for disclosure purposes [62].

As it was already mentioned before, Portugal ceased to be the AIB member by the end of 2015, that means that there is no electronic connection between Portuguese and Estonian registries, so the direct GOs transfer would not be possible. In this case, the only possible solution is the implementation of the Ex – domain cancellation. According to the EECS rules, AIB members (and non – members) may only cancel GOs for use in another EECS domain if:

- It is technically not possible to transfer the GOs to this domain
- The two competent bodies have concluded a Cancellation Agreement
- The cancellation purpose information is stated on the cancellation statement
- The member in question gives the statistical information concerning the cancelled GOs to the other Competent Body and to the AIB general Secretary [63]

However it is important to mention that the Ex – domain cancellations should be limited, and should not become a reason for the countries, which are not AIB members, not to join the European data exchange system [64].

The EECS Rules only allow to employ this mechanism where the GOs transfer is technically impossible, as in case of Portugal and Estonia. With the objective to see the scope of the Ex – domain cancellations, the following Table 2.4 shows some countries where this mechanism was employed [65].

Table 2.4 Ex – domain cancellations by country in 2016 Quarter 3 [65]

	Estonia	Denmark	Finland	France	Ireland	Norway	Sweden
Latvia	812 396	-	100	-	-	6 773	304 404
Lithuania	851 397	-	-	-	-	40 723	-
Slovakia	-	700 521	7 500	198 888	-	626 390	388 896
UK	85 390	4 894 590	151 274	4 221 811	961 872	6 680 363	8 324 135
Portugal	-	-	-	100	-	115 345	-

As it possible to see, in 2016 Norway and Sweden were the leaders in the GOs Ex – domain cancellations in the other countries which are not members of the AIB. The UK was the largest importer of the GOs. Estonia implemented Ex – domain cancellations for its neighbors – Latvia and Lithuania and also for the UK whereas Portugal imported the GOs from France and Norway. So, using Ex – domain cancellations, the GOs would be cancelled in Portuguese registry, but they will not be reflected in the Portuguese statistics, but in Estonian consumption statistics. In the Portuguese registry, it would be necessary to specify that the GOs would be cancelled in favor of Estonia.

The following data should be embedded in an issued GOs [59]: Producer’s name, physical address and contact details; production device name, location, type, capacity, and energy source used for electricity generation; date on which the production device supplied electricity for the first time; energy unit production start and end date; whether and to what extent the producer has received investment support; the time, country, and unique identification number of the issued Guarantee of Origin [59].

2.3 Commercialization and cancellation of the imported GOs in Estonia

When the customer purchases the GOs, he can claim that he consumed renewable energy and the respective GOs must be taken out of the circulation. When it is cancelled, the GO cannot be moved to any other account, and so is no longer tradable. Expired certificates are not valid for cancellation [40]. The corresponding amount of GOs must be cancelled in the database of the GOs issuing body using the cancellation application form, which must include the following information [59]:

- Client's name (in whose favor the GOs are cancelled)
- Client's company registry code
- Reason for cancellation of GOs
- Client type (producer, consumer, electricity seller)
- Client's country of residence
- Client's address

The GOs that are relevant for the cancellation are sorted by production device and expiration date. Both GOs issued for the electricity produced in Estonia as well as GOs imported from foreign states can be cancelled [59].

In order to sell the Portuguese GOs in Estonia, it would be necessary to enter into a contract with the Estonian electricity supplier who would be interested in the purchasing the GOs issued for the produced PV energy. When the agreement upon the price and the quantity of the GOs would be reached, in Portuguese registry there must be cancelled the respective number of GOs in favor of Estonia (Ex – domain cancellation). However, it is important to keep in mind, that GOs from the PV energy are issued in relatively smaller quantities compared to the hydropower and is likely to be slightly more expensive, so the traders and electricity suppliers may have less interest in purchasing these GOs.

When a GOs is sold, the producer receives an extra income of around 0,2 – 0,6 €/MWh. The price of GOs is highly influenced both by age and technology of the power plant, as well as the supply and demand. This is largely determined by the customer's preferences, which differ within the European market. In addition, some customers prefer one specific renewable source above another. These choices are voluntary and can impact the GOs prices for the customers [41]. When the demand for renewable electricity products is increasing, the average GO price is also increasing. This can favorably impact future investments in renewable energy generation and increase the volumes of the renewables. The average price of GO is typically well below

1€/MWh and typically depends on the technology type [37]. Moreover, new plants usually generate higher prices than the older plants. According to the Italian Power Exchange, the average price of GO in Italy in 2016 issued from the produced wind, geothermal, hydro and solar energy was 0,43 €/MWh, 0,21 €/MWh, 0,19 €/MWh, 0,23 MWh, respectively [66].

There were carried out the studies that state that FIT has a primary impact on the project investments. However, adding GOs sales increased the Internal Rate of Return by 2%, which further increased the attractiveness of the project. The study also concluded that GO revenues may improve the ranking of renewable energy methods, such as hydro and onshore wind, over nuclear [41].

3. Photovoltaic self – consumption system sizing

This chapter of the thesis provides the principal steps for the sizing of the photovoltaic solar system for the installation on the roof of the E.Leclerc hypermarket in Lordelo – Guimarães, Portugal. There would be designed a PV system for a self – consumption, that means that its main objective is to supply the building with the produced PV energy and not the sale of the produced electrical energy to the public energy grid.

It includes the study of the orientation and inclination of the solar panels and calculation of the power that can be installed on the roof of the hypermarket. It also aims to evaluate a solar resource at the installation site and to estimate the annual PV production. It includes the study of the sizing of the installation: number of solar panels per string, number of strings, number of inverters, sizing of DC and AC cables and protections. In the final part, there would be realized an economic analysis of the PV self – consumption system with the objective to observe the profits that would be generated with the implementation of the present project.

3.1 The study of the system under analysis

The photovoltaic system for the self – consumption would be applied for the hypermarket located in Lordelo – Guimarães. The solar panels would be installed on the roof of the building. The following Figure 3.1 shows the place of the installation.

Figure 3.1 Aerial photograph of the E. Leclerc complex (Source: Google Maps)

With the objective to facilitate the calculation of the number of the solar panels per strings and number of strings on the roof of the E.Leclerc hypermarket, as it shown in the Figure 3.2, the roof's surface was divided into eight zones: Z1, Z2, Z3, Z4, Z5, Z6, Z7 and Z8. It gives an overview how the solar panels would be distributed over the roof. The usage of the 3D modelling program *SketchUp* and *Skelion* solar design plugin enabled to obtain the ideal number of the solar panels that can be installed in order to maximize the system's output, excluding the harmful effect of shading by neighbouring solar panels or other structures existing on the roof. According to this software, the roof can accommodate 2085 solar panels.

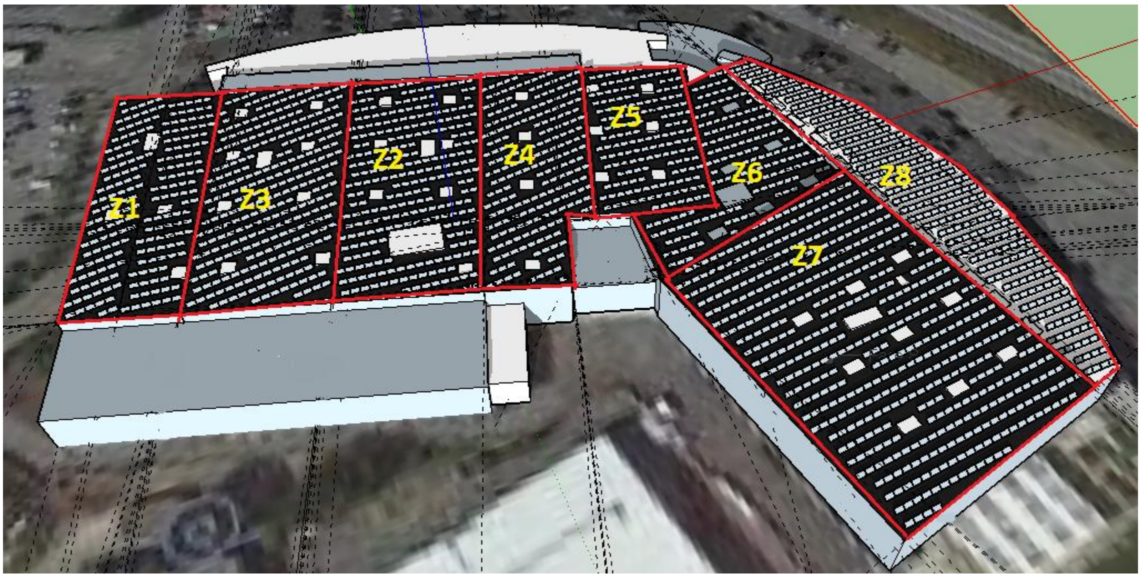

Figure 3.2 Division of the hypermarket E. Leclerc commercial surface into eight zones

The solar panels would be installed with an orientation to the South and with inclination of 35° because it represents the optimum slope for the given installation zone. The inclination angle was obtained by several simulations using different values of the angles in the software *PVsyst* and observing which inclination angle corresponds to the maximum energy generation. In addition to this, another simulation was performed in which the parameter to be altered was the azimuth angle, following the same strategy as in case of the optimal inclination angle of the solar panel, it was concluded that the optimal azimuth for the given site would be 0°.

3.2 Solar resource evaluation at the installation site

Before starting the installation of the PV solar panels, first it is necessary to conduct the studies about the existing solar resource at the installation site. The execution of this step must be carried out very carefully, using an adequate software, since the greater or lesser scarcity of the solar resource can have a significant impact on the viability of the project.

In order to estimate the generation levels of the PV system there was used a tool called *PVGIS* that is available for a free online usage. The use of this tool is very simple, there is just necessary to fill in some data to get the results.

It is important to highlight that in the present PV system project there would be used the solar panels which would have an optimized orientation during all the year, so they will not have any type of solar tracking system that would allow to optimize their position depending on the existing solar resource at any given time. The decision of not using the solar tracking system comes from the elevated maintenance and installation costs that could be hardly compensated. So, as it was already mentioned above, it was defined that the solar panel inclination angle would be 35º.

Through the application *PVGIS*, it was obtained the following information (Table 3.1) concerning the solar irradiation and the energy generation profile by the PV system. As it was already mentioned before, according to *PVsyst*, the roof can accommodate 2 085 solar panels, so using the solar panels of 245 W, the installation would have a total power of 510,8 kW.

Table 3.1 Monthly production forecast for PV system of 510,8 kW (Source: PVGIS)

Fixed system: inclination= 35°, orientation= 0°				
Month	E_d	E_m	H_d	H_m
Jan	1 280	39 700	3,19	98,7
Feb	1 770	49 700	4,44	124
Mar	2 120	65 800	5,48	170
Apr	2 130	63 800	5,61	168
May	2 280	70 700	6,07	188
Jun	2 400	72 000	6,47	194
Jul	2 520	78 300	6,85	212
Aug	2 550	78 900	6,93	215
Sep	2 360	70 700	6,33	190
Oct	1 830	56 800	4,79	148
Nov	1 400	42 000	3,53	106
Dec	1 200	37 200	2,98	92,5
Yearly average	**1 990**	**60 500**	**5,23**	**159**
Total for year	**725 600**		**1 910**	

Where:

E_d: average daily electricity production from the given system (kWh)

E_m: average monthly electricity production from the given system (kWh)

H_d: average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)

H_m: average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)

The data obtained using the online free tool *PVGIS* serves as a basis for a careful sizing of the PV solar system. According to it, the photovoltaic system would generate annually around 725 MWh of electrical energy. Using the obtained information, it is possible to make a first quick analysis of the system's costs. The installation costs per kW of the PV system with the capacity of 510,8 kW can be easily estimated using the following Formula 3.1:

$$Cost\ per\ kW = 2230 \times PI^{-0.1251} \times 0{,}9 = 2230 \times 510{,}8^{-0.1251} \times 0{,}9 = 922\ €/kW \quad (3.1)$$

Where PI – Power to install (kW)

That is, the cost €/kW decreases with the increase of the system dimension. The approximate cost of the whole project can be estimated using the following Formula 3.2:

$$Cost_{project} = Cost\ per\ kW \times PI = 922 \times 510{,}8 = 470\ 957\ € \quad (3.2)$$

According to PVGIS, the PV system would produce annually around 725 000 kWh. Assuming that the installer would be willing to sell the electricity for 0,09 €/kWh, it is possible to calculate the approximate annual profit of the system using the following Formula 3.3:

$$Annual\ profit = W_{annual} \times Price_{kWh} = 725\ 000 \times 0{,}09 = 65\ 250€/year \quad (3.3)$$

3.3 The choice of the solar panels and inverter

This chapter includes all the relevant information concerning the solar modules and inverters that would be implemented in the current project. In addition to this, it also includes the calculation of the optimal distance between the solar panels.

3.3.1 The choice of the solar panels

A key aspect in the development of the PV project is a correct choice of the solar panels. In the solar panel selection process, there were taken into consideration the following aspects: solar panels dimensions, efficiency, mechanical robustness and price. Thus, the choice fell on the solar panels *Mprime*, model *M Series 3R PLUS* of 245 W. According to the product catalogue, these solar panels are quite robust in adverse climatic conditions, covered by the 4 mm glass suitable even for snow and windy climates. Another advantageous feature is that these solar panels have internal textured surface that increases solar radiation absorption. The manufacturers offer 10 years product warranty and a performance warranty that extends over 25 years. During the first year of the exploitation, the solar panel production can maximally decrease by ≤ 3% and the consequent years maximally can decrease by ≤ 0,68% per year.

There are presented two tables which show the main electrical (Table 3.2) and mechanical (Table 3.3) characteristics of the chosen solar panels [67].

Table 3.2 Electrical characteristics of the M Series 3R PLUS, 245 W [67]

Nominal Power (W)	P_{NOM}	245
Average Power (W)	P_{MPP}	247,8
MPP Current (A)	I_{MPP}	8,23
MPP Voltage (V)	V_{MPP}	30,11
Open Circuit Voltage (V)	V_{OC}	37,21
Short Circuit Current (A)	I_{SC}	8,74
Module Efficiency	η (%)	14,9
Temperature Coefficients		
Power	γ (P_{NOM})	-0,420% / ºC
Voltage	β (Voc)	-0,313% / ºC
Current	α (Isc)	+0,058% / ºC

Table 3.3 Mechanical characteristics of M Series 3R PLUS, 245 W [67]

Dimensions	1 663 × 1 003 × 35 mm
Weight	21 kg
Solar Cells	60 Polycrystalline 6 inch cells
Front Cover	Tempered and Textured 4 mm Glass
Back Cover	PPE (Polyester Primer)
Frame	Anodized aluminium (silver / black)

Diodes	3 Bypass Diodes (10,5 A)
Junction Box	IP 65 with 3 Bypass Diodes
Cable	2 Cables of 900 mm
Connectors	Weidmüller WM4 connector

In addition to these data the manufacturer's catalog also provides information on the current and voltage variation of the solar panel in accordance with temperature and irradiance fluctuations which can be seen in the Figure 3.3 and Figure 3.4, respectively.

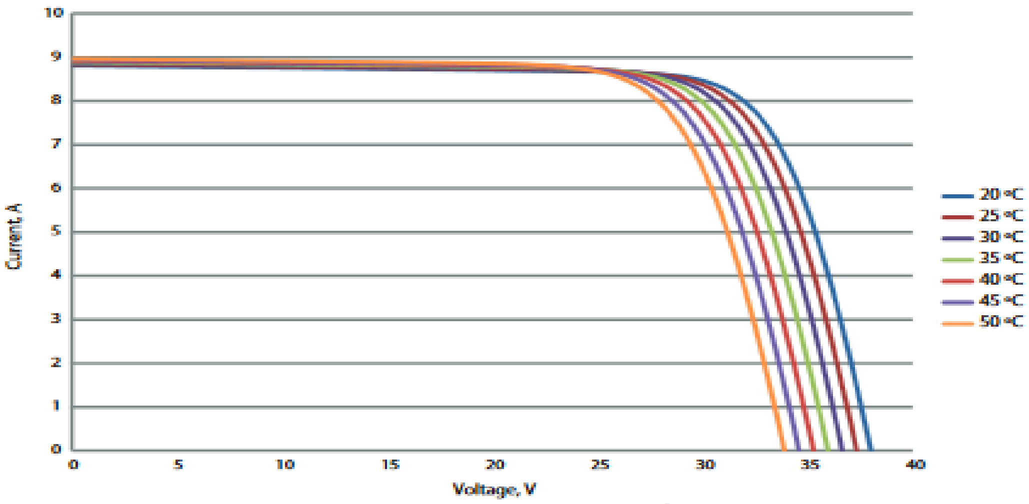

Figure 3.3 I-V curve at different temperatures [67]

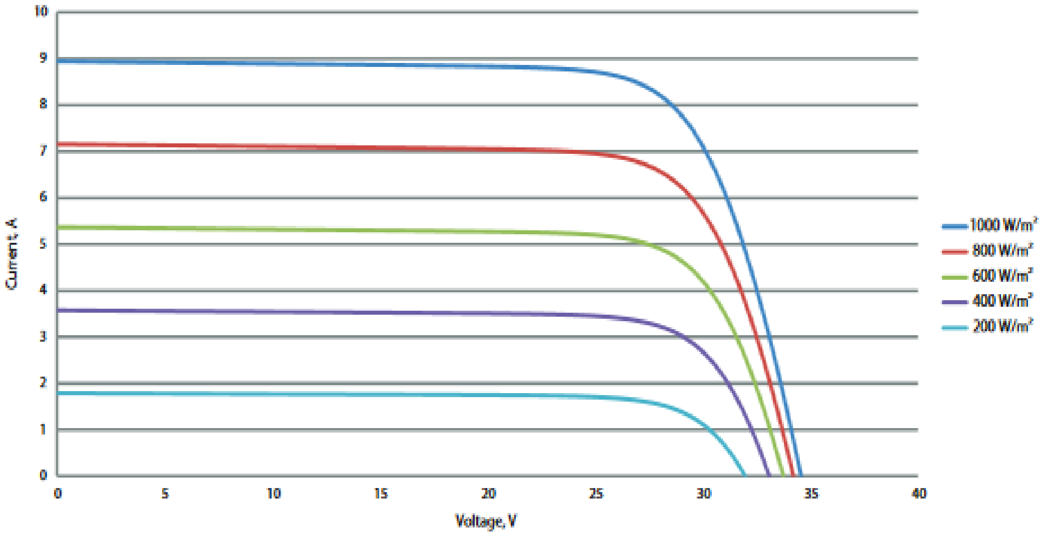

Figure 3.4 I-V curve at different irradiance levels [67]

Through these curves becomes easily noticeable a functional aspect of the solar photovoltaic technology, which consists of the reduced periods of operation in the nominal regime. This fact is justified taking as a scenario when the irradiance at a given day and hour is around 1000W/m^2, it would be very unlikely that the temperature of the solar cells would be just 25 ºC.

3.3.2 Determination of the distance between the solar panels

Using the software *SketchUp*, plugin *Skelion* it was possible to obtain the ideal number of the solar panels to be installed, excluding a situation of the solar panels being damaged by the shading of the other solar panels or the structures already existing on the roof. Using the software *PVsyst* there was set the optimal slope of the solar panels with 35º and azimuth 0º.

The slope of the solar panels would create a shading area. Thus, a certain distance between the consecutive rows of the solar panels must be calculated, so that the shadow caused by one row would not cause shadow to the back row. The following Formula 3.4 presents the calculation of the required distance (d) between the solar panels rows.

$$d = \frac{b \times \sin\,(180° - \beta - \gamma)}{\sin\,(\gamma)} \leftrightarrow d = \frac{1{,}003 \times \sin\,(180° - 35° - 20°)}{\sin\,(20°)} = 2{,}4\,m \qquad (3.4)$$

Where d – Module raw distance

b – Module width

β – Solar panel inclination angle

γ – Shading angle

Shading is an important factor that must be taken into account when designing a PV system and when there are used the mounting structures for the solar panels support. According to the calculation, the distance between the rows must be around 2,4 meters.

3.3.3 The choice of the inverters

When sizing a photovoltaic system, an element of an extreme importance is an inverter. The main task of this device is to transform the energy supplied by the photovoltaic module from DC into AC. Moreover, the inverter has an ability to set the operation of the solar panels at their maximum power point at each time moment.

The choice fell on the inverter *SMA*, the model commercially called "*Sunny Tripower*" 25000TL. The main reasons of the choice were its high efficiency (98,3%); the fact of having MPP tracking, thus allowing to obtain the maximum power at any time moment; the ability of the automatic fault detection in the strings and ability to enable the communications via Bluetooth. Through the inverter’s screen it is possible to observe in real time the value of some parameters such as current power, the energy generation during the day, the total energy generation since the installation of the inverter and the input and output voltage. In addition to this, it is possible to verify the daily evolution of the energy production curve. There are presented in the Table 3.4 the main technical characteristics of the chosen inverter.

Table 3.4 Technical characteristics of the Sunny Tripower 25 000 TL [68]

Input (DC)	
Max. DC power / DC rated power	25 000 W / 25 000 W
Max. Input voltage	1000 V
MPP voltage range / rated input voltage	390 V to 800 V / 600 V
Min. Input voltage / start input voltage	150 V / 188 V
Max. Input current input A / input B	33 A / 33 A
Number of independent MPP inputs / strings per MPP input	2 / A:3; B:3
Output (AC)	
Rated power (at 230 V, 50 Hz)	25 000 W
Max. AC apparent power	25 000 VA
AC nominal voltage	3 / N /PE; 220 V / 380 V
	3 / N / PE; 230 V / 400 V
	3 / N /PE; 240 V / 415 V
AC voltage range	180 V to 280 V
AC grid frequency / range	50 Hz / 44 Hz to 55 Hz
	60 Hz / 54 Hz to 65 Hz
Rated power frequency / rated grid voltage	50 Hz / 230 V
Max. Output current / Rated output current	36,2 A / 36,2 A
Max. Efficiency	98,3%

According to the manufacturer’s catalog, the *Sunny Tripower* is an ideal solution for large – scale commercial and industrial power plants. Within this specific model of inverter there are other sub – models which differ from each other by the amount of the stipulated power and the price – the higher is a power value, the higher is the price of the inverter.

3.4 Implementation of the photovoltaic panels

As it was previously mentioned, the solar panels would be placed on the roof of the hypermarket E. Leclerc. This roof's area would be divided into several smaller areas. The division is presented in Figure 3.5. The main reason for splitting the roof's area into eight areas is due to the fact that these parts of the roof have different slopes, so it would impossible to connect the solar panels in series that would be placed on the surface with different inclination. The largest zone (Z7) would accommodate 506 and the smallest zone (Z6) 154 solar panels.

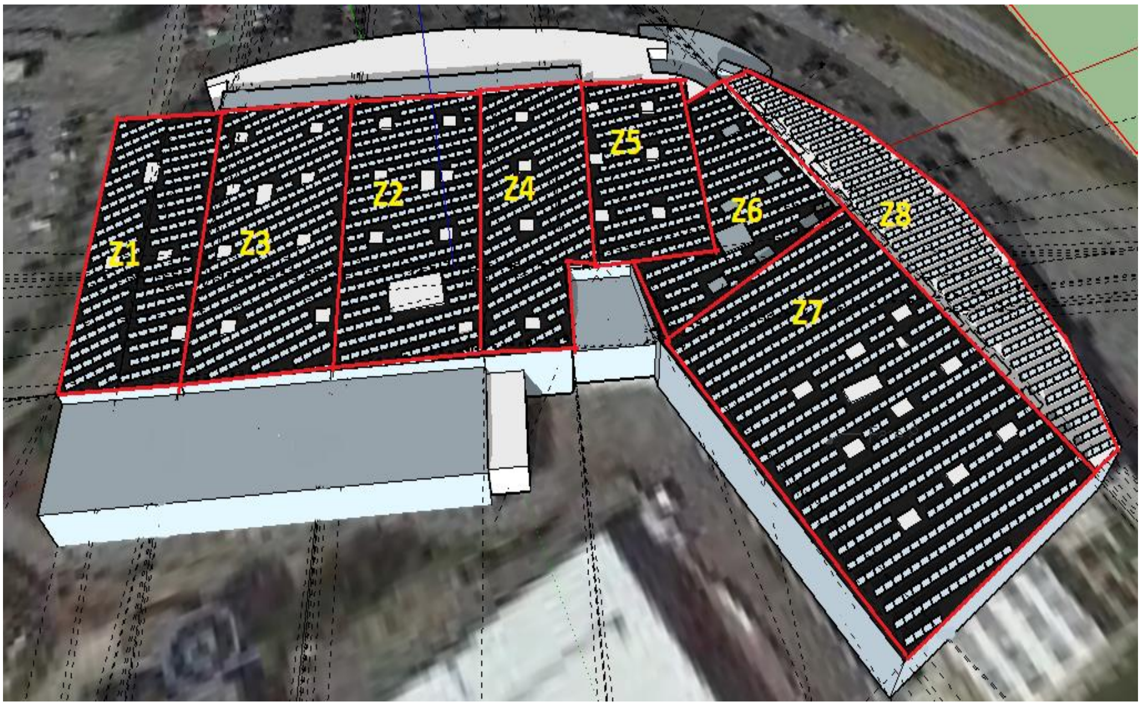

Figure 3.5 Division of the hypermarket E. Leclerc commercial surface into eight zones

After the defining the solar panel type and inverter that would be used for the installation, there must be done maximization of the number of the solar panels per string that can be placed at the hypermarket's roof. Thus, it would be necessary to count the maximum number of the solar panels in each division of the roof and to divide the number of the solar panels by an estimated number of the strings until a maximum number of the panels would be reached.

In order to determine the maximum number of the solar panels to be installed on the roof, there was used a software *SketchUp* and plugin *Skelion*, which allows to introduce into *SketchUp* 3D drawing environment the photovoltaic panels automatically in an efficient way. It permits efficiently to exploit the existing area and at the same time to avoid the panels installation in the areas which are not suitable for it. Using the *Skelion* plugin it was concluded that the roof of the hypermarket could accommodate 2 085 solar panels. Knowing the total number of the solar panels and a power of each one (245 W), it is possible to calculate the total theoretical power of the installation (P_{inst}) (Formula 3.5)

$$P_{inst} = Nº\ panels \times P_{panel} = 2\ 085 \times 0{,}245 = 510{,}8\ kW \quad (3.5)$$

However, with the objective to optimize the number of inverters, some photovoltaic panels should be removed. During the calculation, it was concluded, that the number of the solar panels to be installed would be 2 039. So, it is possible to observe that in relation to the ideal theoretical case, 46 solar panels must be eliminated what is equivalent to say that the total installed capacity of the system would be 11,27 kW less than it was mentioned before. Thus, the calculation of the new power of the installation (P_{inst}) is presented by the following equation using the abovementioned Formula 3.5:

$$P_{inst} = Nº\ panels \times P_{panel} = 2\ 039 \times 0{,}245 = 499{,}5\ kW$$

For each roof's zone, there would be calculated the number of the solar panels associated into the strings. For example, the first roof's division (Z1) would have 11 strings, where each string contains 19 solar panels, so the total number of the solar panels placed in the Z1 would be 209. Knowing the number of the solar panels in each string and a power of each panel, it is possible to calculate the maximum power of the string (P_{string}) using the Formula 3.6:

$$P_{string} = Nº\ panels \times P_{panel} = 19 \times 0{,}245 = 4{,}655\ kW \quad (3.6)$$

Knowing the power of the string and the maximum power of inverter, it is possible to calculate the number of strings which would be connected to one inverter (Formula 3.7).

Thus: $$Nº\ Strings\ per\ inverter = \frac{P_{inverter}}{P_{string}} = \frac{25}{4{,}655} = 5{,}37\ \text{strings} \quad (3.7)$$

Considering the fact, that Z1 has 11 strings, it is possible to calculate the number of the required inverters for Z1 using the Formula 3.8.

$$Nº\ inverters = \frac{Nº\ strings}{Nº\ Strings\ per\ Inverter} = \frac{11}{5{,}37} \sim 2\ \text{inverters} \quad (3.8)$$

Using the following Formula 3.9, it is possible to know whether the obtained maximum power of inverter is within the limits of the power interval. The Formula 3.9 presents the power range of the chosen inverter:

$$0{,}7 \times 25 < Power_{max}\ Inverter\ (kW) < 1{,}2 \times 25 \quad (3.9)$$

So, for the Z1 knowing the number of the strings per inverter and a power of each string, it is possible to calculate the maximum power of the inverter ($P_{max_{inverter}}$) using the Formula 3.10:

$$P_{max_{inverter}} = Nº\ Strings\ per\ Inverter \times P_{string} = 5 \times 4{,}655\ = 23{,}275 < 25kW \quad (3.10)$$

The analogous calculations were realized for the resting seven zones. The following Table 3.5 presents the final results for each of the zones. According to this table the surface of the hypermarket roof would accommodate 99 strings that in total would contain 2 039 solar panels.

Table 3.5 Information concerning the roof's surface divided eight zones

	Z1	**Z2**	**Z3**	**Z4**	**Z5**	**Z6**	**Z7**	**Z8**
Nº panels	209	260	280	210	160	154	506	260
P_{Panel} (kW)	0,245	0,245	0,245	0,245	0,245	0,245	0,245	0,245
V_{MPP} Panel	30,11	30,11	30,11	30,11	30,11	30,11	30,11	30,11
P_{System}	51,205	63,7	68,6	51,45	39,2	37,73	123,97	63,7
Nº inverters	2	3	3	2	2	2	5	3
Nº Strings	11	13	14	10	8	7	23	13
Nº Strings / Inverter	5	4	4	5	4	3	4	4
Nº Panels / String	19	20	20	21	20	22	22	20
V_{MPP} String (V)	572,09	602,2	602,2	632,31	602,2	662,42	662,42	602,2
P_{max}/String (kW)	4,66	4,9	4,9	5,15	4,9	5,39	5,39	4,9
P_{max}/Inverter (kW)	25,605	21,233	22,867	25,725	19,6	18,865	24,794	21,233
$P_{inverter}$ (kW)	25	25	25	25	25	25	25	25

It is possible to observe that two zones (Z1 and Z4) have the maximum power of the inverter higher than 25 kW. This happens because in Z1 and Z4 each inverter includes five strings instead of four.

The global information (number of the solar panels, inverters and the power of the whole system) are presented in the Table 3.6.

Table 3.6 Global data concerning the divided eight zones

Nº panels	2039
Nº inverters	22
P_{system} (kW)	499,55

With the objective to get a better idea concerning the area occupation, knowing the dimensions of the solar panel it is possible to obtain the area of each panel and calculate the area that is occupied by the solar panels per string (Formula 3.11).

$$Area_{panel/string} = Area_{panel} \times Nº\ panels/string = 1{,}627 \times 19 = 30{,}913\ m^2 \qquad (3.11)$$

In addition to this, knowing the area of each solar panel and a number of the panels of the whole PV system, it is possible to determine which area of the roof would be actually covered by the solar panels (Formula 3.12):

$$Area_{system} = Area_{panel} \times Nº\ panels\ of\ system = 1{,}627 \times 2\ 039 = 3\ 317{,}45\ m^2 \quad (3.12)$$

3.5 Data introduction into *PVsyst* calculation software

The next step would be the implementation of *PVsyst* software. First, in this software there is required to choose the option "Project Design". After, there would appear a sub – menu, where would be requested to choose the type of the project and where the option "Grid Connected" must be chosen, since this project aims for the self – consumption PV system sizing where the excess of the electricity generation would be delivered into the energy grid.

Once these options have been chosen, first there must be specified the installation location, which, as previously mentioned, would be Lordelo – Guimarães. Secondly, there must be chosen the solar panel and inverter as well as the number of the strings and the number of the solar panels, which make up each of them. All these options can be observed in the following Figure 3.6. As it was previously mentioned, the installation surface of the current project would be divided into eight zones, so in the *PVsyst* environment there would be inserted separately the data for each zone (subarray).

Figure 3.6 The choice of the solar panels and inverters in software PVsyst

Next, for the adequate software performance, it is necessary to define the details concerning the inclination of the panels and azimuth. These options can be observed in the following Figure 3.7.

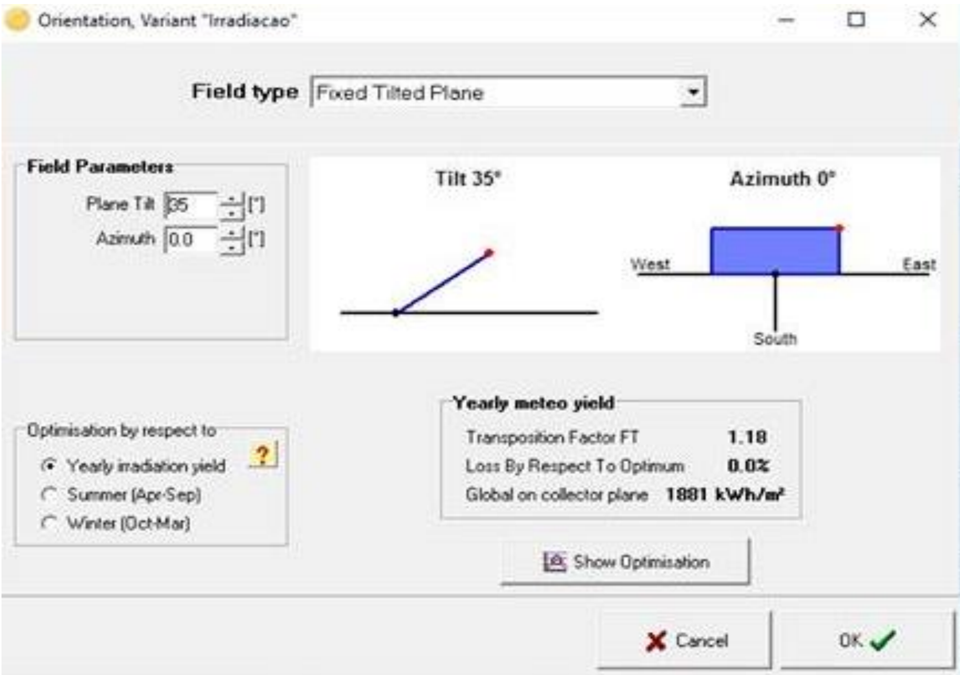

Figure 3.7 The choice of the slope of the solar panels and azimuth at the installation site

3.6 Simulation in *PVsyst* software

After the introduction of all the relevant information in the *PVsyst* environment, there were carried out the simulations with the objective to examine the feasibility of the project over its lifespan, which according to the manufacturer of the solar panels, is estimated to be around 25 years. As soon as the necessary simulations were carried out, the *PVsyst* generated a report, providing various information on the project. Regarding the system losses, it is possible to visualize its total value and distribution in following Figure 3.8.

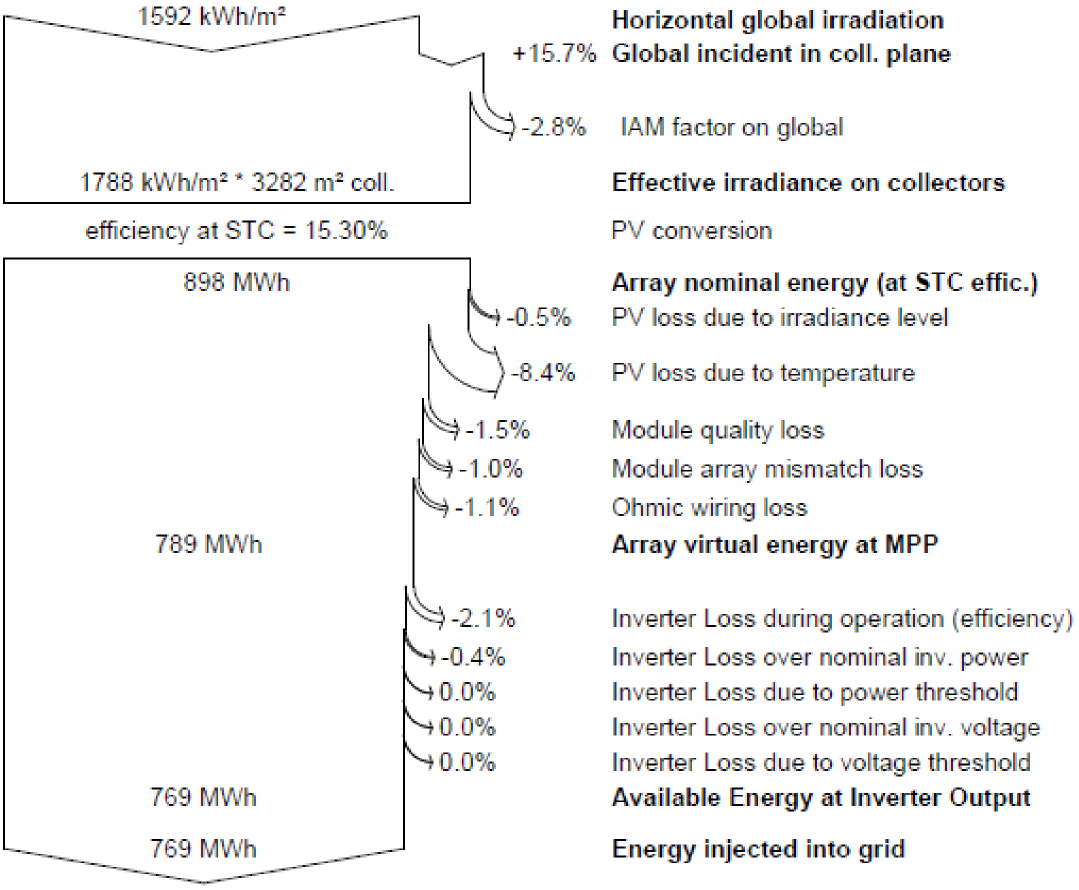

Figure 3.8 Loss diagram resulting from the simulation in PVsyst environment

From this figure, it is possible to perform an analysis on the losses of the whole installation. First, it is possible to see that the system's annual energy generation would be around 769 MWh. Starting with the ohmic wiring losses, it is possible to verify that these represent just around 1%, which at first sight seems a very small value considering the cables extension used in the project. This happens due to the fact that at this stage there were considered just DC cables, which normally have very low losses. The AC cables were not included in these statistics, since they have a small length and since they have a considerable section, they would have few impact on the overall system losses. In addition to this, it is also possible to see other sources of the losses, which, at first sight, may not seem significant, but when analysing the data, it is possible to receive a better notion of their global weight. For example, temperature related losses, which represent around 8%, occur essentially because the solar panels cannot reach their maximum theoretical output above a certain temperature. Moreover, this figure also presents inverter losses accounting for around 2,5%.

The *PVsyst* report also provides another figure where there is possible to observe the distribution of the system's losses and the energy production during one operational year. It can be observed in the Figure 3.9. It is possible to verify that the production levels reach the highest values in the summer months. However, the losses are also more pronounced since the increase in the ambient temperature has a detrimental effect on the solar panels performance resulting in losses increase.

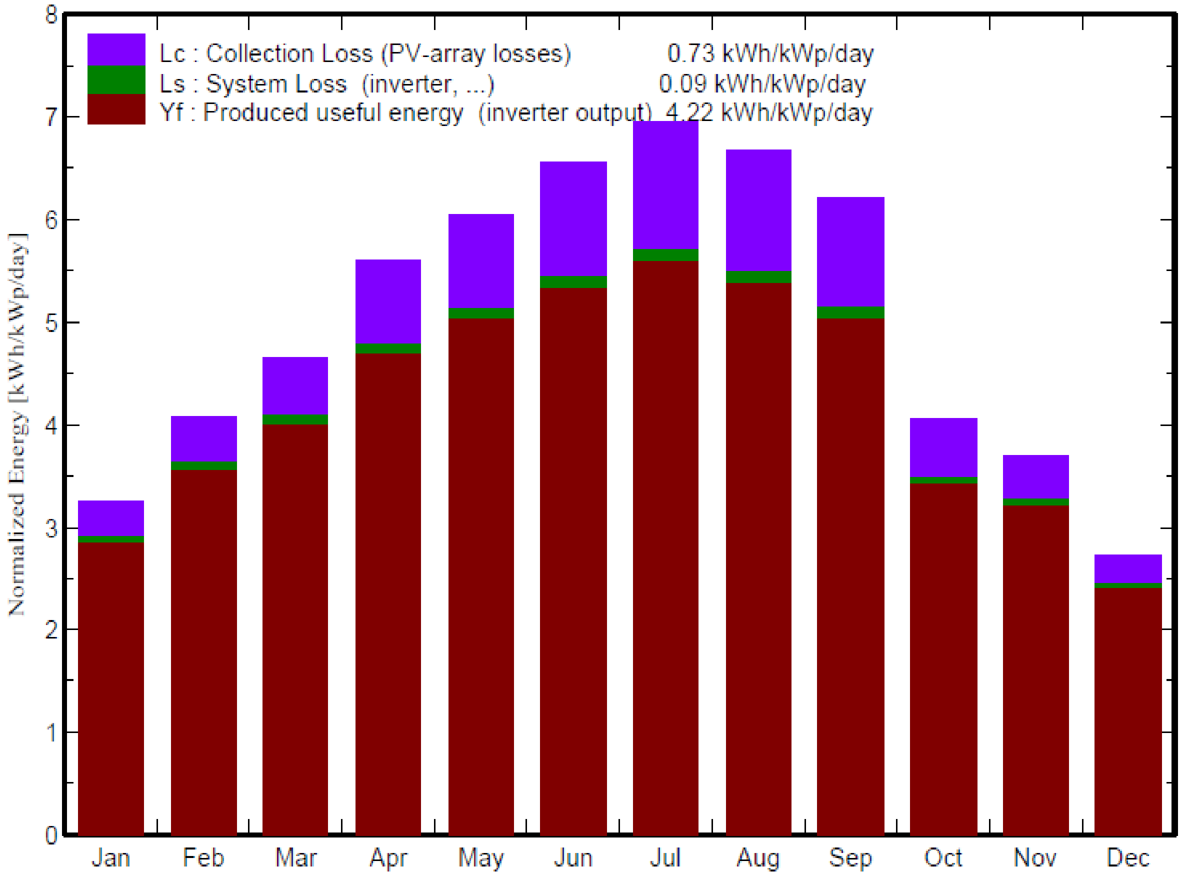

Figure 3.9 Annual power generation and system losses

For the proper functioning of a solar PV system there is a set of relevant measures that must be taken into account, which can be seen in the Table 3.7.

Table 3.7 Global results of the most relevant variables obtained by the simulation for the period of one year

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	58.2	24.07	9.93	100.7	98.2	45.16	44.23	0.879
February	77.6	35.83	10.72	114.3	111.4	50.93	49.92	0.874
March	116.9	62.61	12.77	143.9	139.8	63.46	62.19	0.865
April	153.6	62.73	13.54	167.9	162.9	71.82	70.32	0.839
May	192.6	82.20	16.01	187.6	181.4	79.75	78.09	0.833
June	211.0	71.57	18.74	196.6	190.1	81.79	80.01	0.815
July	225.4	67.30	19.57	215.3	208.7	88.64	86.72	0.806
August	196.8	64.86	20.21	206.9	200.9	85.28	83.45	0.808
September	153.1	48.34	18.73	186.4	181.7	77.26	75.62	0.812
October	91.8	43.55	16.61	125.9	122.4	54.23	53.11	0.845
November	66.4	28.81	12.56	111.1	108.2	49.34	48.37	0.872
December	48.1	23.82	10.56	84.6	82.3	38.14	37.35	0.884
Year	1591.5	615.67	15.02	1840.8	1788.2	785.78	769.37	0.837

Legends:

GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

From this table, it is possible to draw some interesting conclusions concerning the behaviour of the system over the period of one year. Firstly, there is a marked difference between the global irradiation received by the solar panels that are placed on a horizontal plane (*GlobHor*) and the irradiation received by the solar panels, which are inclined with desired slope (*GlobInc*). The irradiance received by the solar panels in the horizontal plane is considerably lower in comparison with the inclined solar panels. It is also possible to notice that in the summer months, the amount of irradiance received by the solar panels, which do not have any inclination, is very close, or even may surpass the amount of the irradiance received by the solar panels with the adjusted slope. However, it is also observable that in the winter months the irradiance received by solar panels that are placed on a horizontal plane is much smaller when compared to the solar panels with the adjusted inclination. In this way, it is possible to conclude that it would be extremely interesting to implement a system of the solar trackers with the objective to increase the efficiency of the system. However, this hypothesis was not analysed in the current project since it would increase the costs of the system in a significant way. In the column (*E_Grid*) there is also possible to observe the amount of the total energy produced, which corresponds to around 769,37 MW.

The systems losses have already been analysed from a more general point of view. However, the *PVsyst* also provides a table where the information concerning the inverter losses (Table 3.8) is given in a more detailed way.

Table 3.8 Detailed inverter losses

	EOutInv	EffInvR	InvLoss	IL Oper	IL Pmin	IL Pmax	IL Vmin	IL Vmax
	kWh	%	kWh	kWh	kWh	kWh	kWh	kWh
January	44228	97.9	1029	931	0.000	98.6	0.000	0.000
February	49918	98.0	1146	1009	0.000	136.5	0.000	0.000
March	62191	98.0	1456	1266	0.000	190.2	0.000	0.000
April	70319	97.9	2121	1503	0.000	618.1	0.000	0.000
May	78087	97.9	2023	1659	0.000	364.0	0.000	0.000
June	80014	97.8	2091	1778	0.000	313.5	0.000	0.000
July	86717	97.8	2366	1923	0.000	443.5	0.000	0.000
August	83453	97.9	2215	1822	0.000	392.6	0.000	0.000
September	75619	97.9	2093	1640	0.000	453.1	0.000	0.000
October	53110	97.9	1266	1116	0.000	149.2	0.000	0.000
November	48365	98.0	1040	975	0.000	66.0	0.000	0.000
December	37346	97.9	838	796	0.000	42.0	0.000	0.000
Year	769367	97.9	19685	16417	0.000	3267.3	0.000	0.000

From the Table 3.8 it is possible to verify that the losses in the maximum limits of MPP are not zero (*IL Pmax* column). This occurs when one inverter includes 5 strings. As it was already mentioned before, in this project there are the two zones – Z1 and Z4 in which the power of the strings would be higher than the inverter's power. So, there would be the time periods, when the inverter will cut some power yielded by the solar panels, as possible to observe from the Table 3.8, during the year there would be cut around 3 267,3 kWh, that is an average of 8,95 kWh/day).

It should also be noted that at first sight the PV system represents a good production potential. However, more definitive conclusions would be made during the project economic viability analysis, where there would be analysed which costs and profits the given project represents.

3.7 Sizing of the DC wiring and protections

One of the fundamental aspects when sizing the PV system is the calculation of the minimum cross section of the conductors that would be employed in the current installation. The cables can be divided into three groups, as they extend through the system from the strings until LV transformer station:

- Group 1. The cables belonging to this group are DC and they establish a connection between the PV panel strings and the junction boxes. They are characterised by good levels of electrical security and weathering resistance. Since they are used for outdoor installations, they are designed to withstand the temperatures above 90°C.

- Group 2. The cables belonging to this group are DC and they are aimed to establish a connection between the junction box and the inverter.
- Group 3. The cables belonging to this group are AC and they establish a connection between the inverters and the LV transformer station.

3.7.1 DC cable sizing

In order to determine the cross – sectional area of the cable, it is necessary to take into account the expected values of the current that will circulate in it. For this, the most unfavourable situation must be considered (under a high temperature), since the higher is the temperature, the higher is a current, thus ensuring that the cable would withstand the remaining current values at lower temperatures. Considering the value of a short – circuit current (I_{SC}) at a temperature of 35°C (approximate extreme ambient temperature for the installation site), the current – carrying capacity (I_z) can be calculated using Formula 3.14:

$$I_z \geq 1{,}25 \times I_{SC} \leftrightarrow I_z \geq 1{,}25 \times 8{,}83 \leftrightarrow I_z \geq 11{,}0375\ A \tag{3.14}$$

Where I_{SC} – Short – circuit current (A)

I_Z – Current carrying capacity (A)

In the current project, for the connection establishment between the PV solar panel strings and junction boxes, there was chosen a cable model "TOP SOLAR PV ZZ-F (AS) from the manufacturer "Top Cable" [69]. The Table 3.9 indicates the current – carrying capacities and electric parameters for different cable cross – sectional areas:

Table 3.9 Nominal currents of the cable TOP SOLAR PV ZZ-F (AS) [69]

Cross-section mm^2	Open air A	Surface A	Voltage drop V/A·km
1 x 2,5	41	33	23,0
1 x 4	55	44	14,3
1 x 6	70	57	9,49
1 x 10	98	79	5,46
1 x 16	132	107	3,47
1 x 25	176	142	2,23
1 x 35	218	176	1,58

Analysing this table and considering the value of the previously calculated current – carrying capacity of the cable, it is possible prematurely define that the cable cross section of 2,5 mm^2 would be sufficient. However, there are more factors to consider when choosing the cross – sectional area of the cable, such as losses. The higher is the cable cross section, the lower are the losses. In this way, it was verified that the use of cable with a cross section of 4 mm^2 would be more advantageous, since it contributes to more significant losses reduction. However, the cable with this cross section represents higher initial investment when compared with the cables of 2 mm^2 cross section.

It must be ensured that the chosen inverter has the ability to withstand a possible voltage drop in the cable in such way, that the difference between the maximum voltage of the inverter (V_{MPPmax}) and the maximum voltage drop of the cable (ΔV_{cable}) would be situated within the controllable voltage range (Formula 3.15).

$$390\,V < V_{MPPmax} - \Delta V_{cable} < 800\,V \tag{3.15}$$

Where V_{MPPmax} – Maximum MPP voltage (V)

ΔV_{cable} – Cable voltage drop (V)

The cable extensions were approximately calculated for each of the eight zones using a software *SketchUp*. Considering that in the worst scenario a string would have a length of around 270 meters, with the following Formula 3.16 it is possible to calculate the cable maximum voltage (ΔV_{MPPmax}):

$$\Delta V_{MPPmax} = \frac{\Delta V_{cable} \times L_{max} \times 2}{10 \times I_{max}} \leftrightarrow \frac{14{,}3 \times 270 \times 2}{10 \times 11{,}0375} = 69{,}8\,V \tag{3.16}$$

Where V_{MPPmax} – Maximum MPP voltage (V)

V_{cable} – Cable voltage drop (V)

L_{max} – Maximum cable length (m)

I_{max} – Maximum current in the cable (A)

As it can be seen from the following Equation 3.17, it is possible to conclude that even in the most unfavourable scenario, the voltage in the DC cable would remain within the controllable range.

$$390\,V < 800 - 69{,}8 < 800\,V \leftrightarrow 390\,V < 730{,}2\,V < 800\,V \rightarrow OK \tag{3.17}$$

3.7.2 String diodes

In this project, there were not employed the blocking diodes, since these have some drawbacks – namely frequent failures that may lead to the string isolation. These faults are difficult to detect and they reduce energy production and consequently, may cause voltage drops leading to the greater losses in the whole system.

3.7.3 String fuses

In each string, there must be present two fuses, one for each cable terminal (positive and negative). The main purpose of the fuses is to prevent a high reverse current flow in the strings. The fuses operate at a certain voltage (V_f) which value can be obtained by application of the following Formula 3.18. In the current project, in the worst scenario there would be a maximum number of the solar panels connected in series 22 and open circuit voltage (V_{OC}) would be 37,21V.

$$V_f = M \times 1{,}15 \times V_{OC} \leftrightarrow 22 \times 1{,}15 \times 37{,}21 = 941{,}4\ (V) \tag{3.18}$$

Where M – Number of the solar panels in series of each string

V_{OC} – Open circuit voltage per module (V)

The nominal current (I_N) of a fuse for each string can be calculated using with the following Formula 3.19:

$$I_N > 1{,}56 \times I_{SC} \leftrightarrow 1{,}56 \times 8{,}83 \leftrightarrow I_N > 13{,}7\ A \tag{3.19}$$

Where I_{SC} – Short – circuit current of each string (A)

Considering the obtained values, the choice of the fuse model fell on LF316PV from the manufacturer Hager [70]. The technical data of LF316PV is presented in the following Table 3.10.

Table 3.10 Hager LF316PV Fuse Specification [70]

Nominal current	16 A
Rated Voltage for use for DC	1 000 V
Operating temperature	-25°C to 70°C
Fuse size	10,3 × 38 mm

Considering the fact, that the solar panels of the whole installation would be associated into 99 strings and that each string must to be protected by 2 fuses, in total there would be employed 198 fuses.

3.7.4 DC switch

The DC switch must be installed between each inverter and the corresponding row of strings with the objective to electrically isolate these zones. In order to realize the sizing of the DC switches, there must be considered the voltage and current. In relation to the current (I_{NDC}), it could be calculated using the following Formula 3.20:

$$I_{NDC} > 1{,}25 \times I_{SC} \leftrightarrow 1{,}25 \times 8{,}83 > 11{,}03\ A \tag{3.20}$$

In relation to the voltage (U), its value could be calculated for the maximum voltage of the solar generator using the following Formula 3.21:

$$U > U_{OC} \leftrightarrow 42{,}1 \times 22 \geq 926{,}2\ V \tag{3.21}$$

Where U_{OC} – The open – circuit voltage in each string at a temperature of -5°C (V)

The choice of the DC switch that would suit a given PV system fell on the product of Hager, the model SB432PV [71]. The technical data of the chosen DC switch is presented in the Table 3.11. The system would require 22 DC switches.

Table 3.11 Hager SB432PV DC Switch Specification [71]

Nominal current	32 A
Number of poles	4P
Rate voltage for use in DC	1000 V
Operating temperature	- 40 to 65°C

3.8 Sizing of the AC wiring and protections

3.8.1 AC cable sizing

As it is known, the installation would have 22 inverters connected to the AC side through the cables that would make the connection between them and from LV Distribution Board to the LV Transformer Station. However, LV Transformer Station usually has just 5 useful outputs, so the 22 inverters cannot be directly connected to the LV Distribution Board. Therefore, there was realized a distribution of the cables by Switch cabinets. For this, in the current project there would be used 6 Switch cabinets of type X, constituted by 5 tri – blocks, one of them is connected to the LV Transformer Station, since they allow the connection of the 5 cables to the LV Distribution Board (6 Switch Cabinets × 4 = 24 available inputs).

Thus, it is necessary to size two types of cables:

- Cable connecting each inverter to the Switch cabinet
- Cable connecting the Switch cabinet to the LV Distribution Board

The study of the AC cables is started by the cables that would establish a connection between inverters and respective Switch cabinets. The AC cable must be sized in order to verify the heating conditions and the voltage drop condition. On the other hand, according to RTIEBT (Technical rules for LV electrical installations), the minimum cross section of the cable should be 6 mm^2. Thus, the verification of the conditions was carried out with this minimum cross section of the four – pole cable (three – phase, neutral and protective conductor) which also has Cross – linked polyethylene (PEX) insulation due to its good insulation characteristics.

The nominal current of the conductor should be higher than the maximum current of the inverter. Considering that the cable would be made of copper and that it would be fixed directly to the wall, it is possible to observe using RTIEBT table that the reference method would be C [72]. Next, referring to RTIEB Table 3.12 for three active conductors, in case of the cable with the cross section of 6 mm^2 and PEX insulation, the maximum acceptable current would be 52A.

Table 3.12 Permissible currents for the reference methods A, B and C [72]

Cross Section of the Conductor (mm^2)	**Reference method**		
	A	B	C
Copper conductor			
1,5	17 A	20 A	22 A
2,5	23 A	28 A	30 A
4	31 A	37 A	40 A
6	40 A	48 A	**52 A**
10	54 A	66 A	71 A
16	73 A	88 A	96 A
25	95 A	117 A	119 A
35	117 A	144 A	**147 A**
50	141 A	175 A	179 A

Since the maximum output current of the chosen inverter is 36,2 A, it can be confirmed that the maximum acceptable current of the cable is much higher (52 A), so the condition is verified.

The maximum voltage drop (ΔU) can be calculated using the following Formula 3.22:

$$\Delta U = R_p(90°\mathrm{C}) \times L_{max} \times I_B \tag{3.22}$$

Where R_p *(90°C)* – Phase resistance of the conductor for the maximum temperature of 90°C, since it is isolated by PEX (Ω)

L_{max} – The maximum length of the cable (from inverter to Switch cabinet) (km)

I_B – The maximum cable service current (equal to the maximum output current of the inverter) (A)

The value of the resistance must be correlated since it represents its value on an operating temperature of 20°C, requiring the resistance value for the temperature of 90°C. Through the tables of the RTIEBT, it is possible to know that for the cross section of 6 mm^2 R_p (20°C) = 3,08 Ω/km and that the correction coefficient K_θ = 1,2765 [73].

Thus, using the Formula 3.23, the voltage drop would be:

$$\Delta U = R_f(20°\mathrm{C}) \times K_\theta \times L_{max} \times I_B = 3{,}08 \times 1{,}2765 \times 0{,}01 \times 36{,}2 \cong 1{,}423\ V \tag{3.23}$$

Next, using the Formula 3.24 it must be verified, which percentage this value actually corresponds to, since the voltage drop cannot be more than 3%.

$$\frac{\Delta U}{U} \times 100 = \frac{1{,}423}{230} \times 100 = 0{,}62\% < 3\% \tag{3.24}$$

Thus, the voltage drop condition was verified. Therefore, the cable minimum cross section of 6 mm^2 would be sufficient for guaranteeing the safety conditions. The cable choice fell on XV 5G6 [74].

For the sizing of the cable that would establish a connection between Switch cabinet to the LV Distribution Board, first it would be necessary to verify the heating condition. The maximum current (I_{max}) that would circulate in the cable is the sum of the maximum currents of four inverters that are connected to each Switch cabinet. The calculation is shown by the following Formula 3.25:

$$I_{max} = Nº\ inverter \times I_{\max of\ inverter} \leftrightarrow 4 \times 36{,}2 = 144{,}8\ A \tag{3.25}$$

Where $I_{max\ of\ inverter}$ – Maximum output current of the inverter (A)

Thus, it would be necessary to find a cable with a maximum permissible current higher than 144,8 A. Consulting the above mentioned RTIEBT tables (Table 3.12), for the same reference method (Method C) and the same type of the cable (copper, PEX insulation), the maximum permissible current that satisfies the heating condition is 147 A, which corresponds to the cable of cross – sectional area of 35 mm^2.

The verification of the voltage drop condition is similar to the previously performed (Formula 3.23), only changing the service current (the sum of the currents of four inverters connected to the Switch cabinet) and the cable section changing (35 mm^2) its resistance R_f (20°C). So, the voltage drop is presented by the following expression:

$$\Delta U = R_f(20°\text{C}) \times K_\theta \times L_{max} \times I_B = 0{,}52 \times 1{,}2765 \times 0{,}01 \times 144{,}8 \cong 0{,}968\, V$$

Using the Formula 3.25 it must be verified, which percentage this value actually corresponds to, since the voltage drop cannot be more than 3%.

$$\frac{\Delta U}{U} \times 100 = \frac{0{,}968}{230} \times 100 = 0{,}42\% < 3\%$$

Thus, it is possible to conclude that the voltage drop condition is also satisfied and the choice of the cable for the connection establishment between Switch cabinet to the LV Distribution Board fell on XV 5G35 [74].

3.8.2 Circuit Breakers

The AC circuit breakers are responsible for the protection of each cable that connects the inverters to the respective Switch cabinet, so in the current project there must be used 22 circuit breakers. For the circuit breakers, there must be also verified a short circuit condition: the circuit breaker tripping time (t_p) must be less than the thermal fatigue of the cable (t_{ft}). For this purpose, it is necessary to make various calculations to find out the thermal fatigue of the cable and to calculate three types of the short circuits:

- $I_{sc\_PN\_min}$, next to the inverter (considered that cable that connects the inverter to the Switch cabinet and a cable that connects Switch cabinet to LV Distribution Board)
- $I_{sc\_PN\_max}$, next to the Switch cabinet (considered the cables that connects LV Distribution Board to the Switch cabinet)
- $I_{sc\_3P\_max}$, next to the Switch cabinet (considered the cable that connects the LV Distribution Board to the Switch cabinet)

For the minimum short circuit current (Isc_PN_min) calculation there was considered the resistance at the temperature 90°C and the cables that would connect both the inverter to Switch cabinet and Switch cabinet to the LV Distribution Board. There must be employed the following Formula 3.26:

$$I_{sc\_PN\_min} = \frac{C \times 230}{R_p + R_n} \quad (3.26)$$

Where C – 0,95 (minimum short circuit)

R_p – R phase

R_N – R neutro

$R_p = R_N$

The following Figure 3.10 depicts the scheme for Minimum Phase – neutral short circuit calculation.

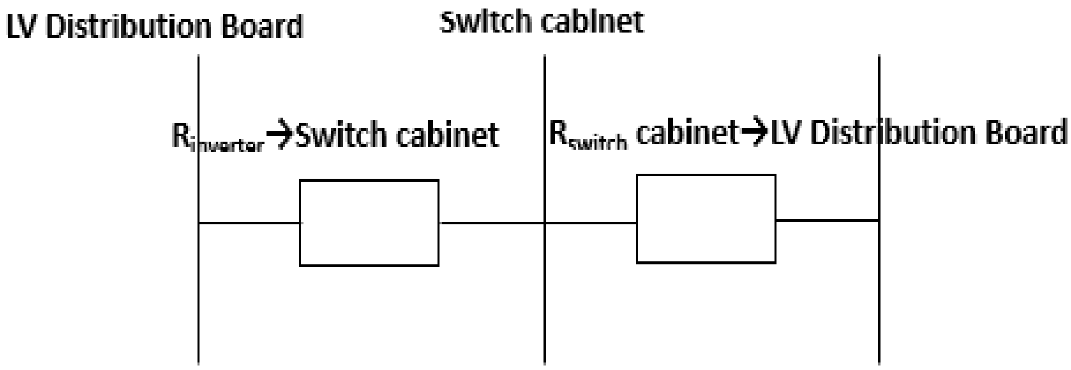

Figure 3.10 Scheme for Minimum Phase – neutral short circuit calculation

The values of the resistance must be used for a maximum cable operating temperature of 90ºC. The values of resistance for the cables of 35 mm^2 and 6 mm^2 must be adjusted for the 90ºC [75].

$R_{\text{Switch Cabinet} \rightarrow \text{LV Distribution Board}}$ (20°C) – 0,524 Ω/km with L_{max} = 10m

$R_{\text{inverter} \rightarrow \text{Switch Cabinet}}$ (20°C) – 3,08 Ω /km with L_{max} = 10m

Turning these values to the temperature of 90°C:

$$Rf_{\text{Sw.C.}\rightarrow\text{LV Dist.B.}} = Rn_{\text{Sw.C.}\rightarrow\text{LV Dist B.}}\,(90°C) = 0{,}524 \times 1{,}2765 \times 0{,}01 = 0{,}006689\Omega$$

$$Rf_{\text{inverter}\rightarrow\text{Sw.C.}}(90°C) = Rn_{\text{inverter}\rightarrow\text{Sw.C.}}(90°C) = 3{,}08 \times 1{,}2765 \times 0{,}01 = 0{,}039316\Omega$$

So according to the Formula 3.28, the value of the minimum short circuit ($I_{SC\_PN\_min}$) would be:

$$I_{SC\_PN\_min} = \frac{0,95 \times 230}{2{\times}0,006689 + 2{\times}0,039316} \cong 2\ 374,7\ A$$

After the calculation, there was obtained a minimum short circuit current of 2 374,7 A and by the following formula it is possible to calculate thermal fatigue time, where K=143 (copper cable insulated with PEX) and S = 6 mm^2 (Formula 3.27)

$$t_{ft} = \frac{K \times S}{I_{sc\_PN\_min}} = \frac{143 \times 6}{2\ 374,7} = 0,361\ s \qquad (3.27)$$

Where K – 143

S – 6 (mm^2)

$I_{sc\_PN\_min}$ – Minimum short circuit current (A)

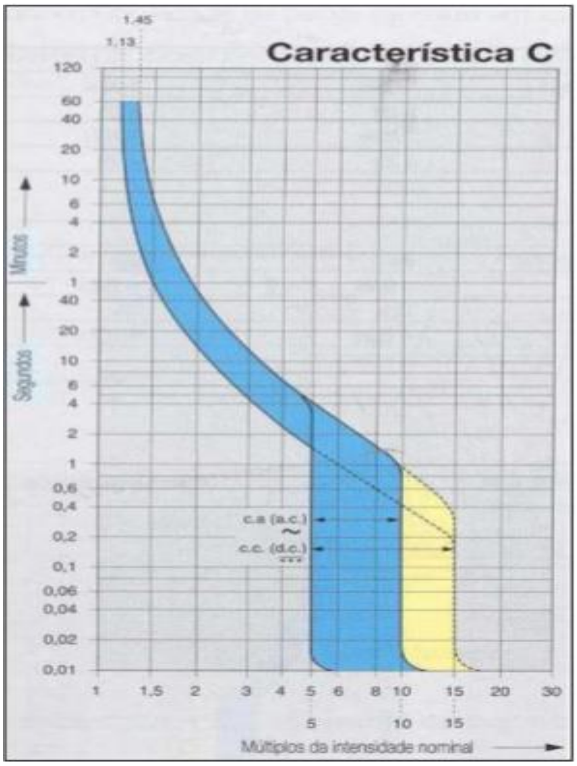

Figure 3.11 C – type circuit breaker tripping characteristic curve

The circuit breaker actuation time must be less than 0,361 s. Referring to the operating curve of the 40 A circuit breaker (Figure 3.11), it is possible to conclude that the actuation time of the protection, for a current of 2 374,7 A/40 A = 59,3 would be around 0,01s, so the condition for this type of short circuit is verified.

For the calculation of the maximum short circuit (Isc_PN_max), it is necessary to take into account the value of resistance at temperature of 20°C, and consider the cable that establishes a connection between the Switch cabinet and LV Distribution Board (10 metres) (Formula 3.28).

$$I_{sc\_PN\_max} = \frac{C \times 230}{R_{phase} + R_{neutro}} = \frac{1 \times 230}{0{,}0524+0{,}0524} = 2\ 129{,}6\ A \quad (3.38)$$

Then it was necessary to use the equivalent scheme in p.u. for the calculation of the three - phase short circuit current (Isc_3F_max) [76].

Where S_{base} (power) – 715 kVA

U_{base} (voltage) – 400 V

$I_{base}(\text{current}) = \frac{S_{base}}{\sqrt{3} \times U_{base}} = 1032{,}01\ A$

$Z_{base}(\text{impedance}) = \frac{{U_{base}}^2}{S_{base}} = 0{,}2237\ \Omega$

With the following Formula 3.29 passing the values of resistance at 20 °C for p.u:

$$R_{Switch\ Cabinet \rightarrow LV\ Distribution\ Board}(20°\text{C}) = \frac{0{,}524 \times 0{,}01}{0{,}2237} = 0{,}0234\ p.u \quad (3.29)$$

From the RTIEBT table [77], it is possible to know the value of the reactance of the cable and pass this value for p.u using the Formula 3.30:

$$X_{Switch\ Cabinet \rightarrow LV\ Distribution\ Board} = \frac{0{,}0783 \times 0{,}01}{0{,}2237} = 0{,}0035\ pu \quad (3.30)$$

Then the calculation of the three - phase short circuit current (Isc_3F_max) would be realised with the Formula 3.31 and Formula 3.32:

$$I_{sc\_3F\_max} = \frac{1 \times 1}{0{,}0234 + 0{,}0035} = 37{,}17\ p.u. \quad (3.31)$$

$$I_{sc\_3F\_max} = I_{sc_{3F\_max}}(p.u) \times I_{base} = 37{,}17 \times 1032{,}01 = 38\ 359{,}8\ A \quad (3.32)$$

The thermal fatigue time would be calculated using the following Formula 3.33:

$$t_{ft} = \frac{143 \times 6}{38\ 359{,}8} = 0{,}022\ s \quad (3.33)$$

For the current of the 38 359,8 A /40 A = 958,9, the circuit breaker tripping would be instantaneous, whereby the condition is verified. It was chosen a circuit breaker with a cutting power of more than 40 kA, 22 circuit breakers of Hager (HMX440) with the rated current of 40 A and 50 kA cutting power [78].

3.9 Project Feasibility Analysis

In order to carry out an economic feasibility analysis of the present project, it is necessary to carry out the estimation of the initial cost of the investment.

3.9.1 Initial cost of the Investment

During the sizing of the various system components, there were made suggestions concerning the equipment that would be used in this project. The searches regarding the prices of the equipment together with the information provided by the professor regarding the prices and other estimations, enabled to realize the study of the initial cost of investment. The following Table 3.13 presents the information about the chosen material, including the manufacturer, quantity and the price per unit.

Table 3.13 List of the required material, its description and price

Material	Manufacturer	Description	Cost (€)
PV solar panels	Mprime Solar (245 W) (0,56 €/kW)	Price per unit	137,2
		Number of units	2 039
		Total cost	**279 750,8**
Inverter [79]	Sunny Tripower (25 000 TL)	Price per unit	2 969
		Number of units	22
		Total cost	**65 319,1**
Transformer	(630 kVA)	Price per unit	31 758
		Number of units	1
		Total cost	**31 758**
Mounting structure	Inversolar	Price per unit	113,8
		Number of units	1 020
		Total cost	**116 076**
Cable DC [69]	Top cable (TopSolar 4 mm^2)	Price for 1000 m	500
		Total meters	11 093
		Total price	**5 546,5**
Cable AC [74]	Cabelte 6 mm^2 (XV 5G6)	Price for 1000 m	4 836,8
		Total meters	70
		Total cost	**338,5**
Cable AC [74]	Cabelte 35 mm^2 (XV 5G35)	Price for 1000 m	31 445,6
		Total meters	20
		Total cost	**628,9**

Fuses DC [70]	Hager (LF316PV)	Price per unit	6,31
		Number of units	198
		Total cost	**1 249,3**
Switch DC [71]	Hager (SB432PV DC)	Price per unit	193,2
		Number of units	22
		Total cost	**4 250,8**
Circuit breakers [78]	Hager (HMX440)	Price per unit	293,6
		Number of units	22
		Total cost	**6 460**
Distribution Cabinets	Type X	Price per unit	1 000
		Number of units	6
		Total cost	**6 000**
TOTAL COSTS			**517 469,9**

These are the initial costs required for the PV installation on the roof of the hypermarket E. Leclerc for the self - consumption. It should be noted, that the costs associated with the maintenance, workforce and licensing there were not considered.

3.9.2 UPAC versus consumption through the energy grid

It is necessary to make a study of the tariffs to be paid for the energy supplied from the grid. There must be considered two aspects:

- Energy injection into the grid: If the PV production is higher than the consumption, the excess of energy would be delivered into the grid
- Energy supply from the grid: If the consumption is higher than the PV production, the energy would be supplied from the grid

The following Table 3.14 presents the annual amount of the energy produced by the PV solar panels, the amount of the energy that was consumed onsite and amount of the excess energy that would be injected into the grid. The data concerning the consumption profile of the hypermarket E.Leclerc was delivered by the client and included the information on hourly energy consumption.

Table 3.14 Annual amount of the energy produced, self – consumed and injected into the grid

PV Production (kWh)	Self – consumption (kWh)	Net consumption (kWh)	Injected into grid (kWh)
770 468	768 672	2 089 724	1 795

It is necessary to calculate the electricity bill for each day without UPAC and with UPAC. For this, it was essential to know the time periods for the summer and for the winter with the objective to know which tariffs to apply to the certain hour (Table 3.15). For this reason there was used the information from ERSE (Energy Services Regulatory Authority) website which provided what kind of period is going to be, depending on the time of the day, day of the week and the season [80].

Table 3.15 Time periods for summer and winter [80]

Winter				**Summer**			
Hour	Sunday	Saturday	Week	Hour	Sunday	Saturday	Week
0	ValleyN	ValleyN	ValleyN	0	ValleyN	ValleyN	ValleyN
1	ValleyN	ValleyN	ValleyN	1	ValleyN	ValleyN	ValleyN
2	ValleyS	ValleyS	ValleyS	2	ValleyN	ValleyS	ValleyS
3	ValleyS	ValleyS	ValleyS	3	ValleyS	ValleyS	ValleyS
4	ValleyS	ValleyS	ValleyS	4	ValleyS	ValleyS	ValleyS
5	ValleyS	ValleyS	ValleyS	5	ValleyS	ValleyS	ValleyS
6	ValleyN	ValleyN	ValleyN	6	ValleyS	ValleyN	EmptyN
7	ValleyN	ValleyN	Off-peak	7	ValleyN	ValleyN	Off-peak
8	ValleyN	ValleyN	Off-peak	8	ValleyN	ValleyN	Off-peak
9	ValleyN	ValleyN	Off-peak	9	ValleyN	Off-peak	Off-peak
10	ValleyN	Off-peak	Peak hour	10	Off-peak	Off-peak	Peak hour
11	ValleyN	Off-peak	Peak hour	11	Off-peak	Off-peak	Peak hour
12	ValleyN	Off-peak	Off-peak	12	Off-peak	Off-peak	Peak hour
13	ValleyN	ValleyN	Off-peak	13	Off-peak	Off-peak	Off-peak
14	ValleyN	ValleyN	Off-peak	14	Off-peak	ValleyN	Off-peak
15	ValleyN	ValleyN	Off-peak	15	ValleyN	ValleyN	Off-peak

16	ValleyN	ValleyN	Off-peak	16	ValleyN	ValleyN	Off-peak
17	ValleyN	ValleyN	Off-peak	17	ValleyN	ValleyN	Off-peak
18	ValleyN	ValleyN	Off-peak	18	ValleyN	ValleyN	Off-peak
19	ValleyN	ValleyN	Off-peak	19	ValleyN	ValleyN	Off-peak
20	ValleyN	Off-peak	Peak hour	20	Off-peak	Off-peak	Off-peak
21	ValleyN	Off-peak	Off-peak	21	Off-peak	Off-peak	Off-peak
22	ValleyN	ValleyN	Off-peak	22	Off-peak	ValleyN	Off-peak
23	ValleyN	ValleyN	Off-peak	23	Off-peak	EmptyN	Off-peak

The information concerning the tariffs was found on the website of ERSE [81] and is presented in the following Table 3.16:

Table 3.16 Tariffs to apply depending on the time period [81]

Fixed tariff (€/day)	**Peak hour (€/kWh)**	**Off – peak hours(€/kWh)**	**ValleyN (€/kWh)**	**ValleyS (€/kWh)**
0,095	0,103	0,0917	0,06638	0,05923

Adding these values of the tariffs to the total tariff for the whole year, using the software *Excel*, the following values were obtained:

- Electricity bill without UPAC = 328 918,59 €
- Electricity bill with UPAC = 240 646,4 €
- Invoice of the energy injected into the grid = 56,24 €

Consequently, it was possible to calculate the annual profit that corresponds to the difference between the electricity bill without UPAC and with UPAC plus invoice of the energy injected into the grid. This profit corresponds to 88 328,43 EUR annually.

3.9.3 Profit and Payback period

Analysing the initial costs associated to the installation of the PV system and knowing the forecasted annual profit from selling the electricity, it becomes possible to obtain an estimation of the benefits resulting from the implementation of the project. It must be noted that for the initial analysis there would be considered that no bank loans would be granted to cover the initial investment costs of 517469,9 EUR, that the solar panels would not reduce its production levels over the time, that no inflation rate would be considered and that the project's life would be 25 years.

With the objective to see how quickly the PV installation would start generate profits, the following Table 3.17 presents the annual cash flows of the project assuming that it would be the owner of the E.Leclerc hypermarket who would do the investments in the PV installation. Thus, the useful life of the project was assumed to be 25 years.

Table 3.17 Annual cash flows of the project

Beginning of the year	Profit	Balance
0		-517 469,9
1	88 328,43	-429 141,47
2	88 328,43	-340 813,04
3	88 328,43	-252 484,61
4	88 328,43	-164 156,18
5	88 328,43	-75 827,75
6	**88 328,43**	**12 500,68**
7	88 328,43	100 829,11
8	88 328,43	189 157,54
9	88 328,43	277 485,97
10	88 328,43	365 814,4
11	88 328,43	454 142,83
12	88 328,43	542 471,26
13	88 328,43	630 799,69
14	88 328,43	719 128,12
15	88 328,43	807 456,55
16	88 328,43	895 784,98
17	88 328,43	984 113,41
18	88 328,43	1 072 441,84
19	88 328,43	1 160 770,27
20	88 328,43	1 249 098,7
21	88 328,43	1 337 427,13
22	88 328,43	1 425 755.56
23	88 328,43	1 514 083,99
24	88 328,43	1 602 412,42

From this table, it is possible to conclude that the installation of the PV solar panels would be a good investment, having an estimated payback period of around 6 years. Using an indicator widely used in the economic area, period of return on investment (PRI), it is possible to calculate the number of years required for the capital invested in an initial phase of the project to be recovered from the financial flows generated throughout the life of the project. This period may accurately be calculated using the following Formula 3.36:

$$PRI = \frac{I}{\frac{CF}{n}} = n \times \left(\frac{I}{CF}\right) = 25 \times \frac{517\ 469{,}9}{2\ 208\ 220} = 5{,}85 \qquad (3.36)$$

Where n – Number of the periods under analysis in the investment project

I – Initial investment of the project

CF – Sum of the cash flows obtained during the life of the project

This indicator is very important since it allows to assess how the investments contribute to the achievement of the results and allows to plan the goals based on achievable results.

4. Commercialization of the Guarantees of Origin

With the implementation of the PV system for self – consumption on the roof of the hypermarket E. Leclerc in Lordelo – Guimarães, with the use of the software *Excel* it was possible to obtain some important values:

- Annual photovoltaic production: 770 468 kWh
- Annual Self – consumption: 768 672 kWh
- Annual energy injected into the public grid: 1 795 kWh

According to the Portuguese Decree – Law No. 153/2014, articles 4, 7 and 31, all the producers of electricity, which was generated from renewable energy sources, should request DGEG the issuance of the Guarantees of Origin, including those that would be issued for self – consumed energy [28]. Concerning the issuance of the GOs for the self – consumed energy, AIB does not have a formal view on this, given that the practices of members differ and there is no legal imperative (that might change under the new Directive).

Currently Portugal is an observer of the AIB, that means that sooner or later it would become its member. However, for now there are no approved rules yet, either for Portugal or for a future "AIB Domain Protocol". The transfer of the Guarantees of Origins from Portugal to another AIB member state is also doubtful, since it is not known, if it is possible to transfer the Guarantees of Origin issued just from the energy injected into the grid or also from energy, which was self – consumed. Since Portugal is not AIB member, there is no connection between the Portuguese and Estonian registries, that means, that it would be impossible to directly transfer the issued in Portugal GOs to the Estonian registry. So, the only possible solution would be "Ex – domain cancellation". With the objective to sell the GOs issued in Portugal, the owner of the installation would need to conclude the agreement with some electricity supplier in Estonia (e.g. *Eesti Energia AS*), who would be interested in the consumption of the GOs issued from the PV energy. Moreover, it would be necessary to reach the agreement concerning the price and the quantity of the GOs that the Estonian electricity supplier would be willing to purchase.

Since there are still no approved rules concerning the implementation of the GOs in Portugal, there would be assumed two scenarios concerning the usage of the issued Guarantees of Origin from the self – consumed energy in Portugal. The first scenario (A) implies that GOs issued both from the energy injected into the grid and energy self – consumed can be transferred to another AIB member state and cancelled on the demand and the second scenario (B) implies that just the GOs issued from the energy injected into the grid can be transferred to another AIB member state and cancelled on the demand whereas the GOs issued from the self – consumed energy must be cancelled internally. In both scenarios, it would be assumed that the owner of the installation would conclude the agreement with the owner of the hypermarket for 20 years, where the installation's owner would be willing to sell the produced PV energy for 100 €/MWh. After the end of the contract the whole PV installation would become a property of the owner of the hypermarket.

4.1 Scenario A

In Scenario A, there would be assumed that both GOs issued for the energy self – consumed and injected into the grid can be transferred to another AIB member state (Estonia) and cancelled on the demand. According to the calculations realized in *PVsyst* and *Excel*, the annual production of the PV system would be around 770 468 kWh, where 768 672 kWh would be self – consumed and 1 795 kWh would be injected into the public energy grid. It would be also assumed that the owner of the installation would sell the electricity to the owner of the hypermarket with the fixed price of 100 €/MWh during 20 years (contract).

Before the installation of the PV system, the owner of the hypermarket would pay annually around 328 918,59 €. So, knowing the annual electrical energy consumption, it is possible to obtain the average electricity price per kWh which the owner of the E.Leclerc paid before the installation of the PV system (Formula 4.1)

$$Price_{before} = \frac{Annual\ electricity\ bill_{without\ PV}}{Annual\ Consumption} \leftrightarrow \frac{328\ 918{,}59}{2\ 858\ 396} = 0{,}115\ €/kWh \qquad (4.1)$$

After the installation of the PV system, the hypermarket would pay annually around 317 513,6€ (what is less than before the PV installation). The average electricity price after the PV installation can be calculated using the following Formula 4.2:

$$Price_{after} = \frac{Annual\ electricity\ bill_{with\ PV}}{Annual\ Consumption} \leftrightarrow \frac{317\ 513{,}62}{2\ 858\ 396} = 0{,}111\ €/kWh \qquad (4.2)$$

It is possible to calculate (Formula 4.3) the number of the Guarantees of Origin that would be issued during 20 years from the energy injected into the grid and the energy self – consumed:

$$Nº\ GOs = \left(Nº\ GOs_{injected\ into\ grid} + Nº\ GOs_{self-consumed}\right) \times project\ life \leftrightarrow \qquad (4.3)$$

$$(768{,}672 + 1{,}795) \times 20 = 15\ 409\ GOs$$

So, according to the realised calculations, during the useful life of the project, there would be generated 15 409 Guarantees of Origin. With the objective to know the revenues that are associated with the trade of the issued GOs, there must be known the price for each GOs. The general prices of GOs from AIB member countries are following:

- Hydro GOs 2017: 0,20 – 0,25 €/MWh
- Wind GOs 2017: 0,23 – 0,28 €/MWh
- Solar GOs 2017: 0,25 €/MWh (the product most Italian)

The cost is certainly low for the supported large and old hydro power, but it is actually a higher amount for new PV arrays for instance. It is also important to take into account that GOs in certain countries can be more expensive. For example, in the Netherlands, the price of one GOs is around 2-3 €.

According to the Finnish electricity supplier *Helen*, the electricity generated from hydropower certified with GOs costs 44,9 €/MWh, whereas the electricity produced with solar, wind and hydro power certified with GOs costs 66,7 €/MWh. The electricity generated with 100% wind power certified with GOs costs 62,6 €/MWh [82].

In Estonia (*Eesti Energia AS*) the average price of the GO is around 0,23 €/MWh. So, considering that during the useful time of the project there would be issued around 15 409 GOs, and that the average price, with which *Eesti Energia AS* would be willing to purchase the GOs would be around 0,23 €/MWh, the revenue coming from the trade of the GOs could be calculated by the following Formula 4.4:

$$Revenues = Nº GOs \times Price_{GO} \leftrightarrow 15\ 409 \times 0{,}23 = 3\ 544\ € \qquad (4.4)$$

So, the total revenues resulting from the trade of the GOs during 20 years would be around 3544 € or 177,2 € annually. The price of the GOs is highly influenced both by age and technology of the power plant, as well as by the supply and demand. It is largely determined by the customer's preferences which differ within the European market. When the demand for renewable electricity products is growing, the average price of the Guarantee of Origin increases, favorably impacting the future investments in renewable energy generation.

The price for a GO is very low when compared to the other incomes and too uncertain. The GO market has currently very low impact on the investor decisions. However, in future, the GOs system can impact the decisions of renewable energy investors, if the GO demand and prices will grow and if the customers would be willing to make long – term commitments to acquire the GOs [41].

The sum of the cash flows obtained during the life of the project would be around 1 160770,27€. Adding to this amount the revenues generated by the trade of the Guarantees of Origin, (1772€) it is possible to conclude that these revenues will have practically no contribution to the total revenues of the project. However, if the price of the GO would be higher, for example 3 €/MWh (like in Netherlands), the revenues from the sale of the GOs would have a greater impact, but still not significant.

4.2 Scenario B

On the vision of AIB, the GOs issued for the self – consumed energy must be cancelled on the demand and cannot be cancelled in the same time when the energy was self – consumed. The Portuguese legislation concerning this procedure is not clear, so there would be proposed a scenario, where the GOs issued by DGEG for the energy self – consumed must be cancelled internally, that means that they must be cancelled immediately after the self – consumption of the produced energy. It seems more logical to cancel these GOs internally rather than cancel them on demand, since the energy would not be injected into the grid, but would be consumed onsite.

So, it would be assumed that just GOs issued for the energy injected into the grid can be transferred to another AIB member state (Estonia). According to the calculations, the annual amount of the energy injected into the grid would be around 1 795 kWh. Using the Formula 4.5, it is possible to calculate the number of the Guarantees of Origin that would be issued during 20 years for the energy injected into the grid:

$$N^{o}\ GOs\ = N^{o}\ GOs_{injected\ into\ grid} \times project\ life \leftrightarrow 1{,}795 \times 20 = 35{,}9\ GOs \qquad (4.5)$$

Where $N^{o}\ GOs_{injected\ into\ grid}$ – Number of the GOs annually issued for the energy injected into the grid (MWh)

According to the calculations, during the useful life of the project, there would be generated around 35,9 Guarantees of Origin from the electrical energy delivered into the public grid. With the objective to know the revenues that are associated with the trade of the issued GOs, knowing that the average price for the Guarantee of Origin that Estonian energy supplier *Eesti Energia AS* would be willing to pay would to be around 0,23 €/MWh, the revenues can be calculated by the abovementioned Formula 4.4:

$$Revenues_{GOs} = N^{o}GOs \times Price_{GO} \leftrightarrow 35{,}9 \times 0{,}23 = 8{,}257\ €$$

Thus, the total revenues resulting from the trade of the GOs issued for the energy injected into the grid during 20 years would be around 8,257 € or 0,41 € annually.

Concerning the self – consumed energy, there would be supposed, that the owner of the installation (investor) would enter into the contract with the owner of the hypermarket E.Leclerc for 20 years. After the end of the contract the PV installation would become a property of the owner of the hypermarket. It would be supposed, that the owner of the installation would sell the electricity produced for self – consumption to E.Leclerc with the fixed price of 100 €/MWh. In addition to this price, the owner of the installation would add more 2 €/MWh, which stands for the Guarantee of Origin. Normally, the price of the GO is well below 1 €/MWh, for example, in Estonia the recent average price was around 0,23 €/MWh. However, for example in the Netherlands, the price for Guarantee of Origin is around 1 - 3 €/MWh, depending on the technology type. The price for the GOs may increase when the demand is growing. In this scenario, it would be assumed that the price for the GOs issued from the self – consumed energy would be around 2 €/MWh since these GOs would be cancelled internally, not on demand.

According to the calculations realised in *Excel*, before the installation of the PV system, the electricity bill was 328 918,59 €. So, knowing the electricity hourly consumption of the year (annual consumption is 2 858 396 kWh), it is possible to see that the average electricity price per kWh which the hypermarket E.Leclerc paid to the electricity supplier before the installation of the PV system was around 0,115 €/kWh (Formula 4.6):

$$Price_{before} = \frac{Annual\ electricity\ bill_{without\ PV}}{Annual\ Consumption} \leftrightarrow \frac{328\ 918{,}59}{2\ 858\ 396} = 0{,}115\ €/kWh \qquad (4.6)$$

Assuming, that the owner of the installation would be willing to sell the produced PV electricity for 100 €/MWh plus 2 €/MWh (the Guarantee of Origin) during 20 years, it is possible to calculate in the *Excel* the electricity bill after the installation of the PV system. So, the price of the electricity during the contract of 20 years can be calculated using the following Formula 4.7:

$$Price_{during} = \frac{Annual\ electricity\ bill_{with\ PV}}{Annual\ Consumption} \leftrightarrow \frac{319\ 050{,}96}{2\ 858\ 396} = 0{,}112\ €/kWh \qquad (4.7)$$

Knowing the electricity bill after the installation of the PV system, it is possible to calculate the price of the electricity after the end of the contract (20 years), when the whole PV installation would become the property of E. Leclerc hypermarket, so the owner of E.Leclerc would not pay 102 €/MWh to the owner of the installation (Formula 4.8):

$$Price_{after} = \frac{Annual\ electricity\ bill_{with\ PV}}{Annual\ Consumption} \leftrightarrow \frac{240\ 646{,}4}{2\ 858\ 396} = 0{,}084\ €/kWh \quad (4.8)$$

The following Figure 4.1 demonstrates the difference in the electricity price per kWh before the installation of the PV system, with the PV installation (20 years of the contract) and after the end of the contract.

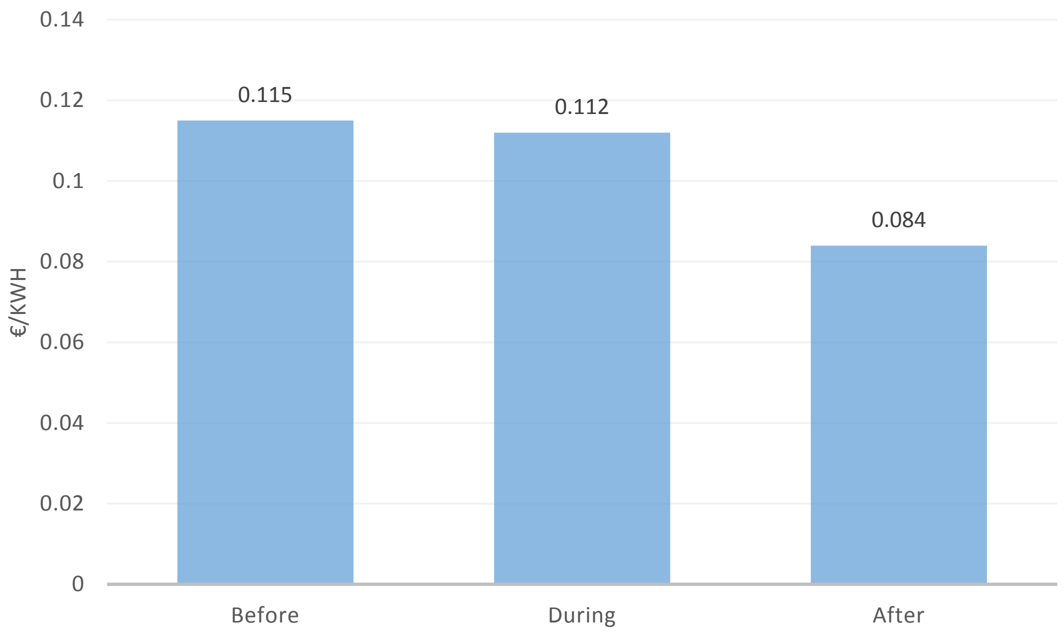

Figure 4.1 The comparison of the electricity price before the PV installation, during the contract of 20 years and after the end of the contract

- It is possible to conclude, that the installation of the PV system on the roof of the hypermarket E.Leclerc can be economically attractive to the owner of the hypermarket, since the price before the installation of the PV system was around 0,115 €/kWh and after the installation (during 20 years of the contract) it would be around 0,112 €/kWh. Moreover, after the end of the contract, the ownership of the PV system would go to the hypermarket, so the electricity price would be even lower: 0,084 €/kWh. There is possible to calculate the total savings on the electricity bill for the owner of the E.Leclerc using the following Formula 4.9:

$$Savings = (Price_{before\ PV} - Price_{during\ the\ contract}) \times 20 + (Price_{before\ PV} - Price_{after\ end\ of\ contract}) \times Energy_{self-consumed} \times 5 \leftrightarrow \quad (4.9)$$

$$(0{,}115 - 0{,}112) \times 20 + (0{,}115 - 0{,}084) \times 768\ 672 \times 5 = 165\ 265\ €$$

Thus, according to the calculations, with the installation of the PV system, the owner of the hypermarket E.Leclerc would save during 25 years around 165 265 €.

In the chapter "Profit and payback period" there have already been realized the economic analysis of the installation assuming that the investments would belong to the owner of the hypermarket. However, in the present thesis, there would be assumed that the investments in the PV installation would be realized not by the owner of the hypermarket E.Leclerc but by the third party. Thus, the following Table 4.1 shows the annual cash flows of the project considering the following aspects:

- The bank loan for 10 years, loan interest 7 %
- The proper investment of 103 493 € (20% of the total investment)
- The duration of the contract 20 years
- Electricity price 102 €/MWh
- Electricity inflation rate 2,5%
- Discount rate 6%
- PV panel production decrease by 3% (first year) and 0,68% decrease (subsequent years)

Table 4.1 Annual cash flows of the project

Year	Investment	Operational costs	Profit	Balance
0	144 891,6	5 174,7	78 588	-71 479
1	63 658,6	4 955	73 713	-66 379
2	57 476,2	4 744,7	70 794	-57 805
3	51 789,7	4 543,2	67 991	-46 147
4	46 562,9	4 350,4	65 299	-31 761
5	41 761,8	4 165,7	62 714	-14 975
6	**37 355,1**	**3 988,8**	**60 231**	**3 912**
7	33 313,4	3 819,5	57 846	24 625
8	29 609,6	3657,3	55 556	46 914
9	26 218,4	3 502,1	53 356	70 549
10	0	3 353,4	51 243	118 439
11	0	3 211	49 214	164 442
12	0	3 074,7	47 266	208 633
13	0	2 944,2	45 394	251 083

14	0	2 819,2	43 597	291 861
15	0	2 699,5	41 871	331 032
16	0	2 584,9	40 213	368 660
17	0	2 475,2	38 621	404 806
18	0	2 370,1	37 092	439 527
19	0	2 269,5	35 623	472 880
20	0	2 173,1	34 212	504 919

So, according to this table, starting from the sixth year, the project will start to generate the profits. It is possible to conclude that the PV installation would be an advantageous solution both for the owner of E.Leclerc and for the owner of the PV installation.

The impact of the consumed electrical energy depends on the sources used for its production. When the electricity is produced from the renewable energy sources (with exception of the use of biomass and municipal solid waste), there are created no emissions of the polluting gases into the atmosphere. With the objective to calculate the CO_2 emissions that originate from the electricity consumption, it is necessary to know the emission factor. The Portuguese emission factor is 0,369 tonnes/MWh [83].

The following Formula 4.10 shows the amount of the CO_2 (tonnes/MWh) which the hypermarket E. Leclerc generates annually without the PV installation:

$$CO_{2_{emissions}} = Consum._{annual} \times Emis.factor = 2\,858{,}369 \times 0{,}369 = 1054\ tonnes \quad (4.10)$$

With the objective to see the share of the energy consumption of the hypermarket E.Leclerc that originates from photovoltaic energy (self – consumed energy), there was realised the following calculation (Formula 4.11)

$$Green\ energy = \frac{Energy_{self-consumed}}{Energy_{consumed}} \times 100 = \frac{768\,672}{2\,858\,369} \times 100 \cong 27\% \quad (4.11)$$

According to this calculation, around 27% of the total consumed energy by the hypermarket E. Leclerc would come from the renewable energy sources, so there would not be generated any emissions. With the objective to obtain the number of the annual CO_2 savings, there was done the following calculation (Formula 4.12):

$$CO_{2_{sav}} = Energy_{self-consumed} \times Emis.factor = 768{,}672 \times 0{,}369 \cong 284\ tonnes \quad (4.12)$$

So, with the installation of the PV system for self – consumption, there would be annually saved 284 tonnes of CO_2. If the owner of the hypermarket would like to have all the consumed energy to be produced from renewable energy sources, he must buy the energy from the public grid which is certified by the GOs.

Since the hypermarket would pay extra 2 €/MWh for the PV electricity, the amount that is paid for the Guarantee of Origin, it could use it for the marketing purposes. For example, some products sold in this hypermarket could have a label saying that the hypermarket uses renewable energy for electricity production. The savings of the CO_2 could be used for the marketing purposes as well.

Conclusion

In the present thesis, there was studied the mechanism of Guarantees of Origin, which aims to prove that the energy was produced from renewable energy sources, namely its issuance, transfer and the cancellation on the example of the photovoltaic energy.

According to the Directive 2009/72/EC, the member states must guarantee that electricity suppliers specify to final customers the contribution of each energy source to the overall fuel mix of the supplier over the previous year. The energy produced from renewable sources must be proven by the Guarantees of Origin. So, the main idea of the Electricity Disclosure is to provide the consumers with the information about power production and try to influence their choice, in order that the selection of a supplier would not be just based on electricity price but also on the electricity quality (green energy).

It is important to keep in mind that while GOs allow customers to make a distinct choice for electricity derived from a specific energy source, and even produced in a specific country, they explicitly have no role in the targets to be achieved by the EU member states. GOs are meant to inform consumers concerning the origin of the electricity, that means for Electricity Disclosure only. This means that if the GOs issued in Portugal are transferred to Estonia and cancelled there, the corresponding energy will contribute to the overall renewable production in Portugal and to the renewable consumption in Estonia. Thus, if Estonia imports GOs, it means that the share of renewables in the total consumption of Estonia is increasing. So, importing GOs does not help a Member State to reach its mandatory national targets, otherwise taxpayers from one country are paying for another country to achieve their targets.

If Portugal would be AIB member, it would be necessary to register as a producer in Portugal and ask DGEG to issue GOs. It also would be necessary to register as a trader in Estonia in order to import the GOs. Registering as a producer in Portugal is not sufficient for exporting GOs to Estonia - it is necessary to have accounts at both ends. However, since Portugal is not AIB member (since December 2015) the only possible way to "transfer" the GOs issued in Portugal to Estonia is using so – called "Ex – domain cancellation", that means that the GOs would be cancelled in Portugal but in favour of Estonia, so the consumption statistics would go to Estonia.

Currently, according to the Portuguese legislation, the GOs can be issued both for the energy injected into the grid and self – consumed energy (Scenario A). The issued Guarantees of Origin must be cancelled on the demand and cannot be cancelled internally (at the same moment when the energy was produced and consumed). Concerning the transfer of the issued in Portugal GOs to the AIB Member states, there are also many doubts, since the current AIB Portuguese Domain Protocol is still under development and it is impossible to claim 100% that the transfer of the GOs issued from the self – consumed energy would be possible. However, in the present thesis there was concluded that the cancellation on demand of the GOs issued from the energy self – consumed is not very logical, since this energy would never be injected into the energy grid.

In this work, there was proposed another scheme for the implementation of the GOs for self – consumed energy (Scenario B). According to this scheme, the GOs issued from the energy injected into the grid must be cancelled on the demand, whereas the GOs issued from the self – consumed energy must be issued and cancelled at the same time (internally). It was proposed that the owner of the PV installation would enter into the contract with the owner of the building where the solar panels would be installed. The duration of the contract would be 20 years and the price for the electricity would be 100 €/MWh. In addition to this price, there would be added more 2 €/MWh, the price that corresponds to one Guarantee of Origin. Thus, the total price of the electricity for the owner of the building would be 102 €/MWh during the following 20 years. For the owner of the hypermarket there are several advantages: the electricity price with the PV installation would be lower when compared without PV installation; since the hypermarket would produce and consume the renewable energy, it can use it for the marketing purposes; after the end of the contract (20 years) the whole PV installation would become the property of the owner of the hypermarket. This scenario is considered to be more realistic, however it does not exist in Portugal and serves just as a proposal.

The trade of the Guarantees of Origin can serve as an additional revenue for the renewable energy producers, however currently its price is well below 1 €/MWh. It is defined by the preferences of the customers which vary within the European market. When compared to the other incomes of the project, the revenues from trading the GOs are very low thus having very low impact on the investor’s decisions. However, in the future, with the increase of the demand for the GOs, its price may increase, so the revenues from trading the GOs may also increase, that means that the investors may become more interested in investing in the renewable energy projects.

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