SUSTAINABILITY CONSULT

IRMÃO BEACH RESTAURANT

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Sustainability consult Irmão beach restaurant

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Preface

This consultancy report was written by a Multidisciplinary project group of five MSc students from the Delft University of Technology. The Multidisciplinary project group consist of five members from the following MSc programs; Bastijn Berenschot and Laurens Pierik from Multi Machine Engineering, Christiaan Gielen from Hydraulic Engineering, and Simon Hammecher and Jesse Blok from Sustainable Energy Technology. The consultancy project was completed as a part of the course Multidisciplinary Project, Civil Engineering Consultancy Project (2021/22), CIE4061-09. This course was part of the elective courses of the different TU Delft MSc programs of the project group members. The consultancy project was carried out in collaboration with Irmão, a beach restaurant in the area of Lisbon in Portugal.

While writing this consultancy report, we assumed the reader not to have any prior knowledge about the topics discussed in this report. In order to make this report comprehensible, it is divided into five parts. The first part outlines the purpose of the study, the requirements of the client and provides information on the context needed to carry out the study. It also discusses how this context information will be obtained. **Part I** is therefore called *context*. **Parts II**, **III**, and **IV** subsequently address the three main themes on which the beach restaurant could improve in terms of sustainability. The three main themes are included in part II, III, and IV, are called *Water System*, *Waste Management* and *Energy System* respectively. Parts II, III, and IV have a similar structure. First, the current state of the three main themes is analysed, then a series of possible solutions are drawn up, from which the best options are then chosen. Finally, these best options are worked out in detail. If you are only interested in a specific main theme, these parts can also be read independently. Subsequently, **Part V** then summarises and presents the impact of all the different best options combined. The conclusion and discussion are presented here as well. Part V is therefore called *Finalization*. The report concludes with the appendixes that contain calculations and data that were too extensive to be included in the text.

We would like to thank Irmão beach restaurant for the great opportunity to carry out our study for the Multidisciplinary Consultancy project at the restaurant. In particular our contact person Thomas Degermann, who helped us with our measurements and for gathering specific sight data of Irmão. Also, we would like to thank the owners of Irmão for their ideas and their commitment to sustainability. During the entire period of our project, weekly meetings were held with our supervisors Prof.dr.ir. L.C. Rietveld and Prof.dr.ir. S.A. Miedema. During the meetings, we were provided with their advice and insights to steer us in the right direction. For this we want to thank both our supervisors Prof.dr.ir. L.C. Rietveld and Prof.dr.ir. S.A. Miedema in particular. Also we would like to thank Prof.dr.ir. van Ommen for answering questions on the formation of thermal NO_x during the combustion of propane.

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Summary

Irmão is a beach restaurant located in the region of Lisbon in Portugal and has been taken over by the new owners one year ago. Since the takeover, the owners of Irmão have been trying to work in a sustainable way, but there is always room for improvement. In addition, Irmão may have to move 100 metres inland due to a possible change in local regulations. Because of the uncertainty in the course of events, this report is written as guideline in order to make the current restaurant more sustainable and as a guideline during the design of the new beach restaurant, should the restaurant have to be relocated.

The aim of the report is therefore to provide beach restaurant Irmão with a consult on how to establish and operate a more sustainable beach restaurant, in present or future times. The study, executed at Irmão, focused on three main themes; the water system, waste management and the energy system. The level of sustainability in these areas is quantified in three ways, namely: the use of resources such as fossil fuels and groundwater; the emission of greenhouse gases CO_2, NO_x and CH_4; the pollution of the direct environment, for example waste that ends up in nature or polluted waste water that flows into the soil. The present and future times refer to the two different scenarios used to implement sustainable solutions. If the restaurant is allowed to stay at its current location, it is referred to as the *Improved Irmão Scenario*. If the location has to be changed, it is referred to as the *Future Irmão Scenario*. For the *Improved Irmão Scenario*, the boundaries and limits of the current restaurant are taken into account and the design is carried out within these limits. For the *Future Irmão Scenario* on the other hand, these limits are loosened and the design is carried out from scratch.

To provide Irmão with a consult how to establish and operate a more sustainable beach restaurant, three steps were taken. First, the current situation of the three subjects is analysed to get a clear understanding of the current situation. This is done to have a baseline against which the final improvements can be compared. Secondly, different solutions to make Irmão more sustainable, within the three main topics, are compared using a multi-criteria analysis to determine the most promising solutions. Thirdly, the final solutions are elaborated for the *Improved Irmão Scenario* and for the *Future Irmão Scenario*.

Regarding the Water system, the analysis showed that the water consumed at Irmão partly originates from the water grid and partly from the borehole in the dunes. The water use is estimated to cause an emission of 182 kg CO_2 annually, leaving little room for improvement in emission reduction as this is a relative low amount. However, the water system is currently not water-efficient because it does not contain any water circularity and the water system does not contain any water saving equipment. Improvements regarding water usage are therefore possible. Regarding waste management, the analysis showed that currently, only residual waste is not recycled. Therefore, the section on waste management focused on making residual waste more sustainable. Regarding the energy system of Irmão, it became clear from the analysis that Irmão currently consumes propane gas and electricity from the local electricity grid. Both the consumption of propane gas and electricity from the local grid contribute to an emission of 26.8 tonnes of CO_2 annually. From all processes carried out during the operation of Irmão, only the consumption of propane gas leads to an emission of NO_x, namely 382 kg NO_x annually.

The *Improved Irmão Scenario* consists of several recommendations for improvements regarding the water system, the waste management and the energy system. Regarding the water system, four types of water-saving devices, five vacuum toilets and three waterless urinals are advised to be installed and circularity to a certain level is advised. In terms of waste management, the *Improved Irmão Scenario* contains two components, namely a composting machine and four underground waste containers. The compost machine can be used to turn different types of residual waste into compost. In this way, CO_2 would be converted into solid form and CH_4 would be converted as well. Regarding the energy system of the *Improved Irmão Scenario*, it is advised to replace the gas water heater by a PVT system. This PV system could be installed on the roof of Irmão. The roof PV system will consist of 54 PV and 8 PVT panels, generating 36.6 MWh per year which is 42.5% of the total electricity demand. In total, the

Improved Irmão Scenario can reduce the annual total water consumption with 53% and the CO_2, NO_x and CH_4 emissions with 39%. 100% and 79% respectively, compared to the current situation.

The *Future Irmão Scenario* also consist of several recommendations for improvements regarding the water system, the waste management and the energy system. Regarding the water system, the same water-saving equipment, vacuum toilets, waterless urinals and circularity are advised to used. In addition, it is advised that the connection to the public network will be closed in order to use only the water obtained from the borehole, which will save Irmão 1108 m^3 of water from the grid. To ensure that this water is drinkable, a pressurised reversed osmosis filtration system with a storage tank and centrifugal pump will have to be installed. Regarding both the water system and the waste management, a biogas plant could be implemented. Furthermore, underground waste containers are also advised to be installed in the waste management section of the *Future Irmão Scenario*. Regarding the energy system of the *Future Irmão Scenario*, besides the gas water heater, it is also advised to replace the gas cook stove and gas deep fryers by the PVT system, an induction cook stove and electric deep fryers. The required electricity could be generated with a PV system on the roof of Irmão and a so called PV Solar Path next to Irmão. This would result in a total of 162 PV and 8 PVT panels with a generation of 102.8 MWh per year, which is sufficient to supply the total annual demand of Irmão. The *Future Irmão Scenario* can reduce the annual total water consumption with 53% and the CO_2, NO_x and CH_4 emissions with 98%, 100% and 79% respectively compared to the current situation.

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Context

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Introduction

Thirty minutes away from the centre of Lisbon you will find a beach restaurant called Irmão. On the way to the restaurant, the Tagus River is crossed by the Ponto 25 de April. Irmão, meaning brother in Portuguese and shown in figure 1.1, is located about twenty kilometres south of Lisbon on the edge of the Atlantic Ocean. The name is not entirely unexpected if one knows that it was initially founded by two brothers and a sister. In the meantime, a cousin and a local friend have also joined the company. The owners described the restaurant as follows: 'Irmão is not a simple bar nor just a restaurant. Irmão is a destination, a place of happiness, where you will surely be able to do what suits you best during a day at the beach'. This is also the impression one gets when looking at the restaurant. Families are present, taking their small children out of the busy city to enjoy the warm summer day, surfers are having a drinks to relax after a day of surfing the waves in front of the restaurant.

Figure 1.1: Aerial view of Irmão.

Irmão has been around for a year now, since the owners took over the restaurant. After the takeover, they tried to distinguish themselves from the other restaurants with their stylish appearance, relaxed beach atmosphere and quality of both service and products. In addition, their goal is to run a beach club that is sustainable. Since the takeover, the owners of Irmão have been trying to work in a sustainable way, but there is always room for improvement.

This chapter serves as an introduction to the report. Section 1 presents the problem statement and the goal of this study. Subsequently, section 2 describes the scope of the study. Section 3 then addresses the customer requirements. Further, in section 4, an explanation is given of what exactly is meant by operating in a sustainable manner. Finally, in section 5, the approach of this study is outlined.

1.1. Problem Statement and Goal

Currently, the desire to become more sustainable is certainly present among owners of Irmão, but an overview of Irmão's current state of sustainability is missing as well as a plan to improve.

The restaurant is located in the dune area, like all the other beach restaurants in the area. Years ago, a law was passed stating that this dune area is protected and therefore building in the area is not allowed. This law intents that all the restaurant in the area of Costa da Caparica have to be move 100 metres land inwards. In recent years, this law has not been enforced. But due to a change in the local government, this law and its observance is under review. As a result, the restaurant may have to move to a location behind the dunes in the near future, which would take away the view of the sea. This would detract from the experience in the beach restaurant and this relocation is therefore undesirable. Because of the uncertainty in the course of events, this report is therefore written for two purposes.

Firstly, it can be used as guideline in order to make the current restaurant more sustainable and thus reduce its environmental footprint. As compensation for its presence in the dune area and in the expectation of being allowed to stay for this reason.

Secondly, the report can be used as an guideline during the design of the new beach restaurant, should the restaurant have to be relocated. By demonstrating ambitious plans for sustainability improvements, a larger amount of available land on which to build the restaurant could be agreed upon, which would allow the restaurant to expand. This leads to the following objective for this study:

> "The goal of this study is to provide beach restaurant Irmão with a consult on how to establish and operate a more sustainable beach restaurant, in present or future times."

As the goal indicates, the report uses two different scenarios. If the restaurant is allowed to stay at its current location, it is referred to as the *Improved Irmão Scenario*. If the location has to be changed, it is referred to as the *Future Irmão Scenario*. For the *Improved Irmão Scenario*, the boundaries and limits of the current restaurant are taken into account and the design is operated within these limits. For the *Future Irmão Scenario* on the other hand, these limits are somewhat loosened and the design is done with more freedom. This entails that the restaurant is designed from scratch.

1.2. Scope of the study

In this section the scope of the project is determined, which indicates the nature, extent and constraints of the project. This states what is in- and outside the scope of the project. First, the topics that are covered in the study are presented, followed by the subjects that are not covered in this study.

1.2.1. In scope

The following items are covered in this study, in order to make Irmão more sustainable.

- **Energy**
  The current energy infrastructure will be analysed and then improved, as it is assumed beforehand that improvements could be made here.This will include determining how Irmão obtains its energy supply, what it is used for and how much is consumed.
- **Water**
  The use of water has an effect on the environmental footprint of the restaurant as well. First of all, due to the fact that over exploitation of water sources can lead to scarcity and decrease in quality. Secondly, due to the amount of energy required to produce clean water and to process waste water. Therefore, extensive study has been carried out into this aspect.
- **Waste**
  The way waste is produced and processed has a big influence on the level of sustainability. Reducing the amount of waste is a great way to reduce the environmental footprint.

1.2.2. Out of scope

The following items are out of the scope in this study.

- **The menu**
  The menu of the restaurant will be considered out of scope. Although the type of food served in a restaurant, and how much food waste is created also has a major impact on the environment. However, the restaurant would like to keep its existing menu and therefore this study will not look into creating a more sustainable menu.

- **The interior of the restaurant**
  The interior is something that gives Irmão a stylish appearance. One could argue that some of the materials used for the interior can have a negative impact on the environmental footprint. However, the style of the restaurant is important for the image of the restaurant, which is why for the purpose of this study the interior falls outside the scope.

- **Rise of the sea level**
  The sea level rise is a big problem around the world. However, for this study, measures to deal with the rising sea level will not be considered. Since the study investigates a beach restaurant, which can be relocated relatively easily if necessary.

- **Transport of people and goods**
  The transport of people and goods is another field of study, in which a lot of improvement can be made from a sustainable point of view. Most of the transport is done by vehicles that are still running on fossil fuels. To address this problem, one has to look to a bigger picture than making Irmão more sustainable, hence it is out of the scope.

- **Human behavior**
  With human behaviour, everything that has to do with the acts of a person with the subsequent consequences is meant. For this study, it is assumed that all humans behave according to the rules and boundaries that are set. Any deviations made by one human individual will not be taken into account.

- **Building materials**
  The building materials used in the construction of the beach restaurant have a considerable impact on the level of sustainability. The current restaurant consists entirely of wood and the owners' wish is to keep it that way, even if Irmão has to move. That is why this study will not look for solutions to make Irmão more sustainable in terms of building materials. In addition, the wood used has been locally sourced and treated according to the Shou Sugi Ban technique, so it already scores very well in terms of sustainability.

1.3. Client Requirements

The main requirement of the client, and therefore also the goal of the project, is that Irmão beach club wants to become more sustainable. Besides the main requirement, there are several additional requirements set by the client. These requirements are discussed in the section below.

- **Optimised sewage system**
  The first requirement of the client relates to the sewage system. Currently the sewage system is not functioning properly. which leads to extra work, high costs and a non-functioning sanitary system. Therefore the requirement is that the sewage system must function properly without requiring significant maintenance. This means that the frequency of maintenance must be decreased to a maximum of once per month.

- **Reliable electricity network**
  Concerning the electricity network, there are two requirements. The first is about the power of the network. The majority of the electricity consumption comes from the use of the many refrigerators and kitchen appliances. These applications require a significant amount of power. Therefore the electricity system must have enough power to supply the whole restaurant. If this is not the case, power breakdowns will occur, which are disastrous for the restaurant's business. Another requirement for the electricity network is that the frequency of the network must be within the permissible margins of the required frequency. This is important for all electrical appliances to work properly.

- **Opened all year round**
  Irmão's main task is to keep the restaurant running successfully. In addition, the main objective of the restaurant is to maximise its revenues. To maximise its revenues, Irmão aims to be open all year round, provided that the weather allows it. Therefore a requirement is that it must be possible to operate the restaurant during the whole year and therefore in different seasons.

- **Heating and Cooling**
  Irmão contains several inside areas where the temperature rises during the day. These high temperatures are caused by the sun on the roof, but also by electrical appliances that generate a significant amount of heat. Therefore, a requirement is that the inside areas must be cooled. The open deck located in front of the bar currently doesn't have a permanent heating system. In summer this will not be a problem but during winter, the temperature will decrease. Therefore, the presence of a heating system on the terrace is a requirement.

- **Preserving restaurant capacity**
  Currently Irmão restaurant can house 60 people, excluding staff, on the deck and has a surface of 80 squared metres. In front of the restaurant is a larger area on the beach with lounges and sunbeds, giving room for another 120 people. Maintaining a minimum capacity of 160 guests in total, will be a requirement for this project. Changes to the design could be made but should not reduce the capacity of the restaurant. If the capacity can be increased with small changes in the design, the owners would be pleased to see that happen.

- **The appearance of the interior and exterior must be preserved**
  Irmão beach restaurant has an interior specifically selected by one of the owners of the restaurant. This design is chosen to create a specific atmosphere. Therefore, it is a requirement that the appearance of the interior and exterior must be preserved, as well as the sea view from the restaurant's deck.

1.4. The concept of sustainability

Since sustainability is a concept that can be broadly interpreted, this study needs to define what exactly is meant by sustainability. In general, a sustainable process is one that does not deprive future generations of the opportunity to meet their own needs (Goodland, 1995). Although this study focuses on a small scale and cannot directly ensure global sustainable development, this ideal is pursued as far as possible. Besides the fact that this study can decrease the negative effect or even ensure a positive effect on the environment. There is another effect, at least as important, that this study can bring about. Namely, becoming an example for similar enterprises. In this way, even though the project takes place on a small scale, it can still have a significant indirect impact on global sustainability. In order to concretely examine whether a restaurant is operating in a more sustainable manner, the degree of sustainability of a process must be quantified. In this study, sustainability of a process in a restaurant is examined in the following three aspects.

Use of resources
The first aspect that indicates the degree of sustainability in this study is the use of resources. Since many natural resources are finite, such as fossil fuels, excessive use cannot guarantee that future generations will be able to meet their needs. In addition, renewable resources are also under pressure. These include for instance forests, rivers and groundwater basins. Since the demand for clean drinking water is rising, it is of great importance that water sources do not become polluted and are used sparingly so that over-exploitation of our water resources is prevented at any cost. Using and reusing resources carefully and as efficiently as possible, with as little pollution as possible, is considered sustainable in this study.

Emission
The second aspect that indicates the degree of sustainability in this study is the emission of gases and particles. Processes around a restaurant can release gases that may have a negative effect on global warming. The gases considered in this study are CO_2, NO_x and CH_4. These are not in itself harmful substances and are in fact essential to life on earth. However, large quantities of greenhouse gases are currently being added to the atmosphere through the burning of fossil fuels, amongst other things, effecting the earth's temperature and therefore makes the emission unsustainable (Ritchie and

Roser, 2017). In addition, the gas CH_4 has a thirty-five times stronger greenhouse effect than CO_2 and it is therefore considered sustainable to convert this gas before being released into the atmosphere. Since emissions occur during the processing of drinking water and the generation of energy through the combustion of fossil fuels, this study considers it sustainable when as little electricity and water as possible is used that emits CO_2 and NO_x. In addition, the amount of CH_4 emissions can be reduced by properly processing waste and human waste. This is therefore considered sustainable in this study.

Contamination of the direct environment
The final aspect that indicates the degree of sustainability in this study is the pollution of the immediate environment. This refers to waste or pollution that can harm flora and fauna but also the quality of the soil, groundwater or ocean. In this study, it is considered sustainable if no waste or pollution ends up in nature that could cause damage. Think of plastic or other poorly degradable materials. In addition, the correct disposal of waste water with minimal contact with the environment is considered sustainable in this study.

An underlying danger of trying to operate more sustainable is that, whether intentionally or unintentionally, the net result will not be more a sustainable operation, but only the appearance of being so. Deliberately pretending that a company is more sustainable than it actually is, is also known as 'greenwashing'. Greenwashing must be avoided at all costs. It can be avoided by taking into account the 7 greenwashing sins compiled by TerraChoice in 2009. The 7 sins include: Hidden trade offs, no proof, vagueness, worshipping false labels, irrelevance, lesser of two evils and finally fibbing.

1.5. Approach

In order to perform this study in a structured manner, it is divided in five stages. The different stages are presented below:

- **Stage 1** - Define & Client requirements
  The first stage of this study consists of two parts. First, the project will be defined, that is formulating the problem definition, goal and scope. This is presented in the current chapter, Chapter 1. Second, requirements of the clients are defined, as it is important to carry out the study within the client's boundaries. These are also presented in the chapter 1.
- **Stage 2** - Methodology
  The second stage describes the procedure for collecting the required data. Chapter 2 presents the methodology for collecting this data. Also, the methods that will be used to compare the different solutions are presented.
- **Stage 3** - Analysis
  The third stage involves carrying out the analysis of the situation in Irmão and its surroundings. In Chapter 3, the current orientation and the blueprint of the Irmão building are elaborated. In Chapter 4, the literature study of the environmental conditions is carried out and then compared with the data obtained from Meteonorm. In Chapter 5, the *Cover Model* is presented, a way to translate water and energy consumption data obtained from a limited period of time to a general year, in order to gain insight into annual water and energy consumption. The exact consumption or creation and thus the environmental footprint is then presented in Chapters 6, 9 and 12 for the water system, waste management and energy system, respectively.
- **Stage 4** - Solutions
  In the fourth stage of the study, multiple solutions will be suggested and weighted against each other on different aspects. In Chapter 7,10 and 13 and , all the solutions along with a comparison will be given for the water system, waste management and energy system, respectively. The most promising solutions are then worked out in detail and presented in chapters 8 and 11 for the water system and waste management respectively. The most promising solutions for the energy system are worked out in detail and presented in chapters 14 and 15.
- **Stage 5** - Final Solution & Conclusion
  The final stage of the study is the combination of the most promising solutions and concludes

with a conclusion and a discussion. In chapter 16, the individual results of the systems are presented together for the *Improved Irmão Scenario* and the *Future Irmão Scenario*. Then, in 17, the conclusion of the study will be given and in chapter 18 the discussion is presented.

For task distribution between members of the team, every member is allocated one main subject:

- Bastijn: Waste
- Chris: Water
- Jesse: Energy
- Laurens: Water
- Simon: Energy

The main subjects are divided to the best of the members knowledge and study background. **Part I**, is written by all the members of the group because this part was important as background for the three main subjects. Furthermore, the task distribution is done in order to give every member some sort of responsibility. But this does not mean each member only interferes with the task he is assigned to. If there is more work on a subject compared to another, someone with a different role will help to lighten the workload. This way, every team member contributes the same amount of time in order to get the study done.

2

Methodology

The tools used during the execution of the stages presented in Chapter 1.5 are explained in detail in this chapter. In order to get acquainted with the current situation at Irmão it is required to perform a literature study and take measurements. A literature study in combination with the program Meteonorm is conducted to gather data on the environment and climate of Irmão and Costa da Caparica. Measurements are conducted in order to make a justified estimation of the average water and energy consumption and the production of waste. Since the measurements take place during a limited period, a model will be created to estimate the production and consumption throughout the whole year. This model is called the Cover-Model. Finally, the multi-criteria analysis to weigh the different solutions against each other is explained.

Literature and Meteonorm
In order to be able to estimate which natural resources will be used to make the restaurant more sustainable, it is first necessary to identify all the resources that are present. Therefore, a literature study is carried out into four main subjects concerning natural resources. These four main subjects are the sun, the water, the wind and the soil. Regarding the sun, the temperature, irradiance, sun height and number of sun hours are considered. Regarding water, the ocean temperature and the amount of precipitation are taken into consideration. Regarding wind, the wind speeds and the direction of the wind are looked at. Finally, the soil present at Irmão is investigated.

In addition to the literature study, hourly data is retrieved from the program called Meteonorm. The retrieved data is specific for the location of Irmão as Meteonorm interpolates data from four different weather stations in the vicinity to create the most accurate representation possible. These weather stations are situated in Lisbon (13km), Cape Carvoeiro (83km), Evora (115km) and Castelo Branco (202 km). The data is retrieved from the year 2020. Meteonorm provides data on temperature, irradiance, sun height, sun hours, precipitation, wind speed and wind direction for every hour of the chosen year. This data will eventually be used to create simulations and models. In order to demonstrate the accuracy of the data collected from Meteonorm, it is compared to data found in literature.

Measurements
Measurements are carried out to determine how much energy carriers and water are consumed and how much waste is created at Irmão. The four types of measurements that are performed during stage two are listed below:

- **Current measurements for every device**
  The peak power is an important factor for the design of a solar panel installation or battery system. In order to obtain the total maximum power requirement of Irmão, it is necessary to measure the current of each electrical device.

  Measuring the current of any device turns out not to be possible at Irmão. Because in order to measure the current through a device, the device has to be connected to a Line Splitter, whereby the Line Splitter makes it possible to determine the current with an ammeter. To do this, each device has to be unplugged and the cable cut open. Besides the fact that cutting open cables is not desirable, the plugs were often in hard-to-reach places, such as behind the cooling. In addition, for large appliances such as the refrigerator, it can be harmful to unplug them for a short period of time. And because the restaurant was in use during the study, the refrigerators were full of products so it was not possible to unplug them for a long time.

Therefore, it is only possible to measure the current at the electrical distribution panel. This panel has 45 different connections that can be measured with an ammeter. The description of the connections is listed below the panel, and will be used to determine which current corresponds to which devices.

It is also important to know if the electricity connection is 1-phase or 3-phase. A 1-phase connection has 1 blue cable and 1 brown cable connection. A 3-phase connection has 1-blue cable, 1 brown cable, 1 grey cable and 1 black cable. This is important because it changes the power calculations for a device.

The following test method is applied to determine the current through all the 45 connections of the electrical distribution panel:

1. Investigate if the electricity connection is 1-phase or 3-phase. If it is 1-phase, continue with the 1-phase instruction. If it is 3-phase, use the 3-phase instruction.

   1-Phase instruction

2. Investigate which devices are connected to the same electricity group of the panel.
3. Place the ammeter around the brown cable.
4. Switch on all the devices of the electricity group at full power.
5. Read the current level from the ammeter.
6. The power can be calculated by multiplying the measured current with the net voltage level.

   3-Phase instruction

7. Investigate which devices are connected to the same electricity group of the panel.
8. Place the ammeter around the brown cable.
9. Switch on all the devices of the electricity group at full power.
10. Read the current level from the ammeter.
11. Repeat step 6,7 and 8 for the grey an black cables.
12. The power can be calculated by substituting the measured current and the net voltage level in the power formula for 3-phase connections.

When the power per electricity group is know, the total maximum required power of Irmão can be calculated.

- **Measurement of energy consumption**
  The energy consumption is determined by daily monitoring the electricity meter at the same hour of the day. Also the amount of propane bottles, used per indicated time, is measured. In combination with the Cover-Model, the monitored data is used to estimate average values of energy consumption throughout the year. Measurements will be taken over a period of time as long as possible, in order to arrive at an estimate that is representative.

- **Measurement for determining maximum flow rate per device**
  There are different types of water using devices present at the restaurant. For example, taps, toilets and dishwashers. In order to obtain a clear picture of the amount of water used per minute by each user, tests should be carried out. The following test method should be applied separately to each water using device present:

  1. Examine the setting at which the flow rate of the water device is the highest
  2. Place measuring cup with pre-marked target volume under the water device.

3. Turn on the water device at the setting with the highest flow rate
4. Turn the water device off again when the target volume is reached.
5. Time in the meantime how long it takes to reach the desired set volume.
6. Note both the timed time it took to fill the cup till the desired level and the exact volume present in the measuring cup.
7. Repeat steps 1 to 6 five times.
8. Compare the obtained data for errors (too much or too little time needed to reach the desired volume). If an error is present, delete the data and repeat steps 1 to 6 to obtain a new measurement (there is a good chance that something went wrong during the test).
9. Based on the correctly obtained values, the amount of litres used per minute during the measurement is calculated.
10. The average of the measurements obtained per user is taken to arrive at the final consumption in litres per minute for each user.

If the diameter of the measuring cup is too small to properly collect all the water from the user, a bucket will be used. The following steps will then be followed:

1. Examine the setting at which the flow rate of the water device is the highest.
2. Place the bucket under the water device for 30 seconds.
3. Turn on the water device at the setting with the highest flow rate
4. Turn the water device off again when the set time has passed.
5. Note exactly how much time has passed. Measure the exact amount of water in the bucket by pouring the water into the measuring cup piece by piece.
6. Repeat steps 1 to 5 five times.
7. Compare the obtained data for errors (Too much or too little time needed to reach the desired volume). If an error is present, delete the data and repeat steps 1 to 5 to obtain a new measurement (there is a good chance that something went wrong during the test).
8. Based on the correctly obtained values, the amount of litres used per minute during the measurement is calculated.
9. The average of the measurements obtained per user is taken to arrive at the final consumption in litres per minute for each user.

- **Water Consumption**
  In order to find out the total amount of water taken from the grid, the water levels are noted at the same time every day. With this, the pattern of daily and weekly water consumption can be determined of the restaurant in total.
- **Measurement of the amount and type of waste**
  The amount of waste produced is measured per bag of waste. In this way, the number of bags of waste thrown away per day is monitored. As the waste is already being separated, the amount of waste produced will be measured immediately by type of waste. The waste is separated according to plastic, glass, paper and other.
  The amount of waste will be measured as follows:

  1. Have 4 different containers for plastic, glass, paper and other.
  2. Make a sheet with 4 different columns for the type of waste.
  3. Put one type of waste together in one bag.
  4. If the bag is full bring it to the container.
  5. When the bag is thrown into the container, cross the according box on the sheet.
  6. Repeat steps 3-5.

After identifying the total amount of energy consumed, water used and waste produced, this must be converted into the total footprint of the restaurant. This involves looking at the amount of greenhouse gases emitted per process, the impact of water use and created non-recyclables.

Data translation

An essential element of this study is the translation of obtained and measured data into data that can be used to represent an average year. The tool that is used for the translation during this study is a regression analysis that investigates the correlation between the consumption of Irmão and the weekly number of covers. Performed on the water consumption, energy consumption and on the waste production. A cover is known as a closing bill.

First, the weekly number of covers throughout the year were determined. For the months of June, July, August and September the exact number of covers could be obtained from the owner of Irmão. However, for the remaining months of the year estimates have been made based on vacation periods in Europe, air temperature, precipitation, number of sun hours a day and data from comparable restaurants. The results are plotted using python as a bar graph and presented in chapter 5. The next step of the translation is the regression. This is executed using a regression function that is able to determine the correlation between two arrays. One array containing known consumption data of certain weeks in which the exact number of covers are also known. The other array holds the corresponding number of covers. The result is an formula in which the weekly consumption can be related to a certain number of covers. In this way is becomes possible to construct the weekly consumption throughout the year based on the estimated number of covers. The same steps are performed for waste production.

MCA analysis

For each system, i.e. water, energy and waste, solutions are devised to make Irmão more sustainable. Only the best of these solutions will eventually be worked out in chapter 16, integrated design. In order to make a choice as to what exactly are the best solutions, one or more Multi-Criteria Analyses will be carried out per system. The choice for the best solution is based on criteria and weighting factors.

The criteria used for assessing the various solutions are divided into two categories. General criteria, which are the same for each system, and subject-specific criteria, which differ for each system. The general criteria consist of cost, ease of implementation, maintenance, environmental impact, aesthetics and lifetime. Cost is a criterion, because Irmão is looking for an affordable solution, so the costs may not increase endlessly. Ease of implementation is important, because Irmão would prefer to remain at the existing location and therefore not want to change too much to the current set-up, as this would involve extra work. The maintenance of the solution must be easy and not too expensive and is therefore also included in the assessment. Making Irmão sustainable also implies that the impact on the environment is as small as possible, so this is also a criterion. The aesthetics of Irmão is very important to the owner and is therefore a general criterion. The lifetime of the solution is also important, as the replacement of materials or equipment will entail additional implementation costs and work.

The subject-specific criteria as well as the weighting factors per criteria are different for each system. These are explained in the relevant chapters of the Multi-Criteria Analysis (water 7, waste 10, energy 13).

3

Analysis of the sight and building

In order to properly specify the energy, water and waste system, it is important to have a good overview of the current building. Therefore this chapter will elaborate on the current building. First in section 3.1, the geographical location of Irmão is presented. Then, the orientation of the building is discussed in section 3.2. Next, in section 3.3, the surroundings of the building are discussed. Then, in section 3.4 the top view of Irmão is presented and provides a description of different areas of Irmão. Hereafter, in section 3.5, the side and front view of Irmão are provided. Eventually in section 3.6 the building materials are briefly discussed and in section 3.7, the walking path towards Irmão is presented.

3.1. Geographical location

Irmão beach restaurant is located on the Costa da Caparica south of Lisbon, below the Tagus river. Praia da Castello is the exact beach that is adjacent to Irmão. Costa da Caparica is located in the civil parish of Caparica e Trafaria, which forms part of the municipality of Almada. This municipality is part of one of the 18 districts of Portugal, named Sétubal. Costa da Caparica has 14038 inhabitants and is well known for its long coast.

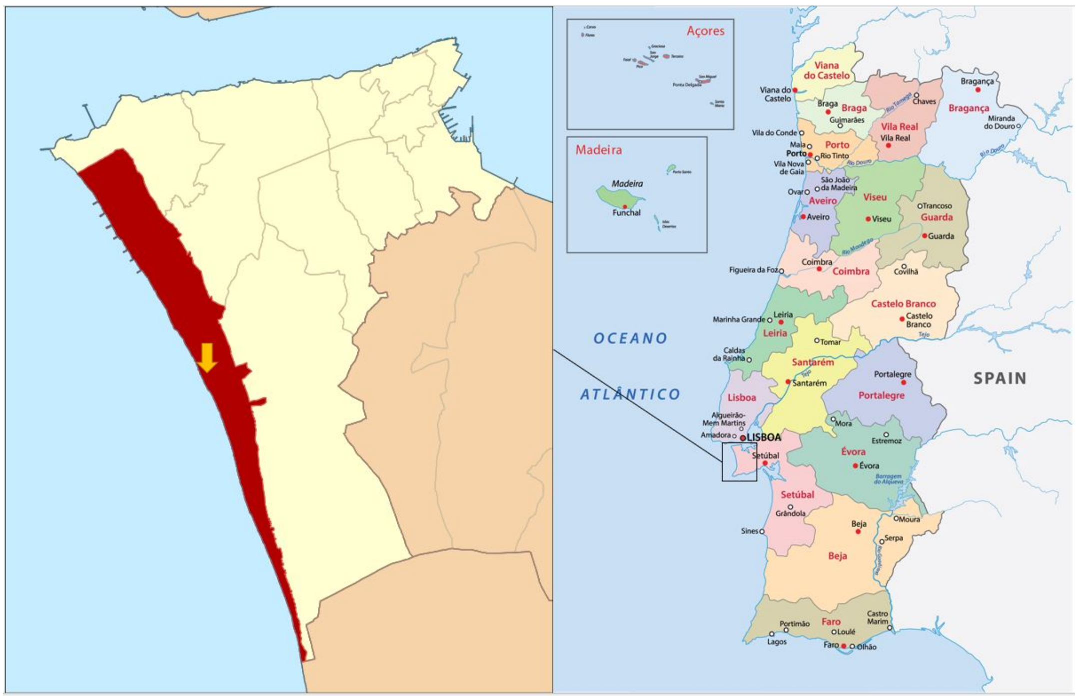


Figure 3.1: Left, a map of the region Almada where Costa da Caparica is depicted in red. Right, a map of Portugal with all the districts (WorldAtlas, 2021).

3.2. Orientation of the building

The orientation of the building is important because it will influence the climate of the building. The orientation determines how the sun falls on the building and how the wind passes through the building, what will lead to temperature changes (Albatayneh et al., 2018). Irmão is already built and therefore the orientation is determined. However, the orientation of the building will influence future designs to make the building more sustainable. Besides, the design of a solar panel systems is affected by the orientation of the building. The topographic top view of Irmão is shown in figure 3.2.

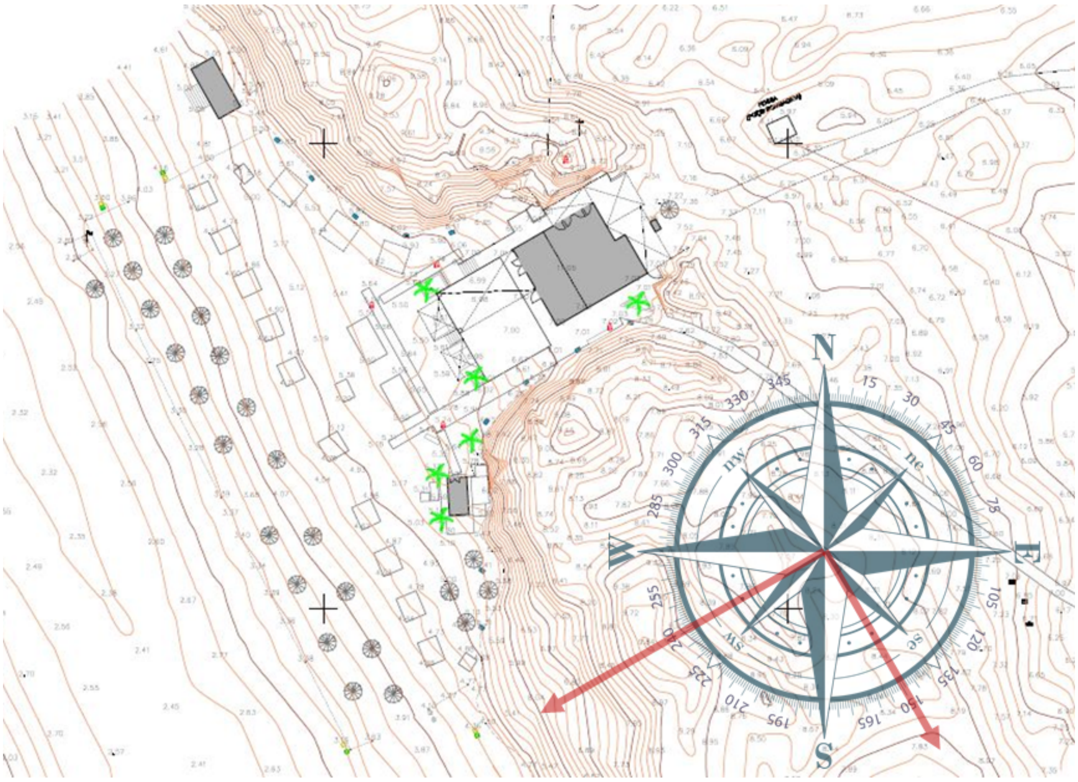


Figure 3.2: Topographic view and orientation of Irmão.

In figure 3.2 it can be seen that Irmão is built in line with the dunes and in a cove of the dunes. The cardinal coordinates are indicated in the right-hand corner of the figure. This shows that Irmão is orientated between West and South West what is also described as 240°degrees in the cardinal coordinate system.

3.3. Surroundings of Irmão

As can be seen in figure 3.2, there are no others buildings in the vicinity of Irmão. In a radius of 100 metres, there is nothing higher than the roof of Irmão. This means that the view is not obstructed by anything. This means that the so-called sky view factor (SVF) has a value of 1. If the view were completely obstructed, the SVF would have a value of 0.

The amount of light reflected from an object is known as albedo. With an albedo of 0, all incoming light is absorbed, which is the case for perfectly black objects. An albedo of 1 means that all the light is reflected. This is the case with perfectly white objects. Since the exact albedo of natural objects is often difficult to estimate, it is approximated. Sand, and thus the beach, has an approximate albedo of 0.35 (Bralower and Bice, 2007). The vegetation of the dunes around Irmão has an albedo of 0.17 (Markvat and Castalzer, 2003).

3.4. Top view current building

Irmão beach restaurant consists of one floor which is built on wooden pillars. Under the wooden pillars, a small storage area for surf gear is located, but this is not used for the restaurant itself. The total surface of Irmão without the beach lounges area, is roughly 240 m^2. In figure 3.3, the top view of Irmão is shown. The areas of the building are displayed with different colors and marked by a specific letter. The figure includes the cross-section of the side and front view indicated with SV and FV, respectively. In table 3.1, the areas with their letter and their surface area (m^2) are given.

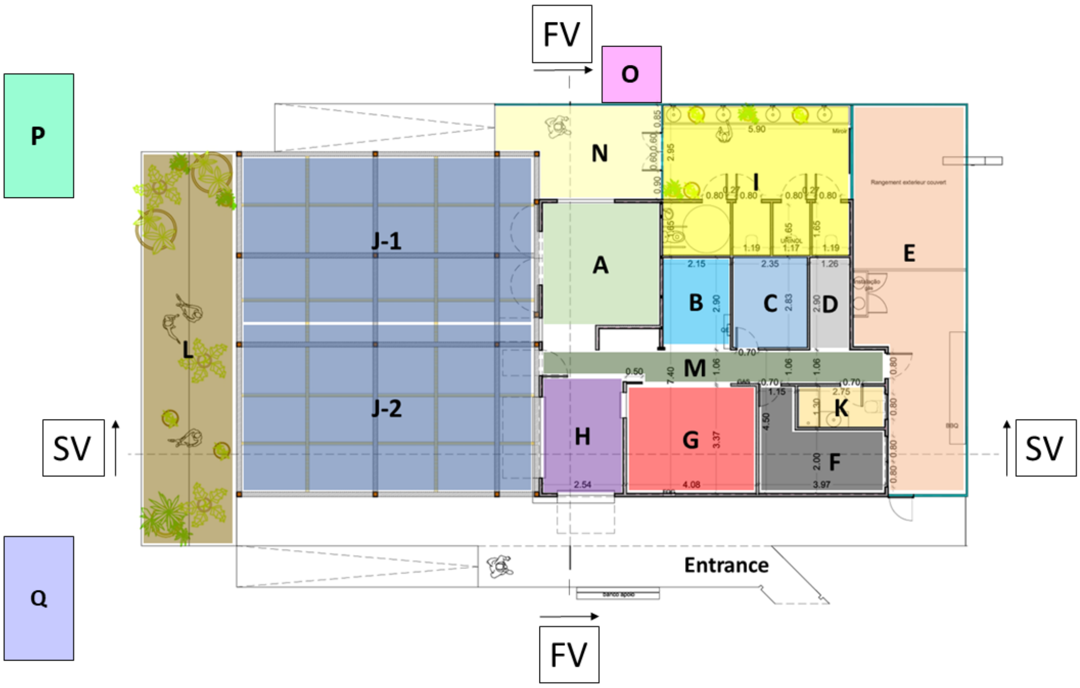


Figure 3.3: Top view of Irmão with the areas indicated with different colors and letters.

Table 3.1: The areas of Irmão with their corresponding letter and surface area in m^2.Legend of figure 3.3.

Letter	Area	Surface area (m^2)
A	The shop	16.1
B	Dishwashing area	6.2
C	Pizza Bakery	6.7
D	Storage room	3.7
E	Back house	43.5
F	Office	9.4
G	Kitchen	13.7
H	Bar	8.6
I	Public toilet	17.4

Letter	Area	Surface area (m^2)
J1 + J2	Restaurant deck	84
K	Private toilet	3.6
L	Beach lounges	540
M	The corridor	15.5
N	Toilet corridor	11.9
O	Public shower	2
P	Surf school	14.4
Q	Gypsy wagon	10.5

In this table, it can be noticed that the restaurant deck is 84 m^2, which is 1/3 of the total surface area of the building. This is relatively little compared to the extra space of 384 m^2 added by the beach lounges. At the beach there is also an extra bar located called the Gypsy wagon, depicted with the letter Q. The shower is located outside the building close to the toilets and is depicted with the letter O. The surf school is depicted with the letter P and is located around 20 meters away from the restaurant.

The areas of Irmão are used for different purposes and therefore have different requirements in terms of energy and water consumption. Due to the limited possibilities for expansion and the fact that Irmão want to remain its guest capacity, it lacks space. Because of this, every area of the building must be used optimally. For example, irmão's stockroom is located under the deck to save space. In appendix A.3, a list of devices is given per area of the restaurant. This list is sorted by water systems, energy appliances and others. Looking at the water system, it can be stated that most of the water consumption takes place in the dish washing area, the bar, the public toilet, the private toilet and the shower. In section 6, a detailed analysis about the water system is provided. This includes a specific water consumption map of Irmão.

The energy consumption of Irmão takes place in all the areas. The consumption per room is widely varying. Some rooms only contain devices that provide lighting, other rooms have large refrigerating containers. Relatively large energy consuming areas are the kitchen, the pizza bakery, the bar and the back house. In section 12.4, a comprehensive description of the electrical devices is given. As far as the waste system is concerned, all areas are also considered. Waste is produced in almost all areas but it is stored at area E, the back house, where waste bins are placed. However, these bins are not large enough to store all the waste during the day. Therefore a large waste storage is located outside the restaurant close to the parking area.

3.5. Side and front view of current building

The side view is given in figure 3.5. It shows that the roof above the inner area has a slight angle of 13°. In figure 3.4, the top view of the restaurant with corresponding roof sections is given. The sloping roof at the seaside, has a surface area of 45 m^2. And the sloping roof above the backside of the restaurant has a surface area of 62 m^2. The outer areas L and J, are not fully covered by a roof. Only half of the restaurants deck, depicted with the letter J-1, is covered by a roof. The roof is transparent and flat. The other part of the restaurants deck, depicted by the letter J-2, and the backside of the restaurant, depicted with the letter E, are covered with a foliage net. The public toilets, depicted with letter I, are partly covered with a wooden flat roof.

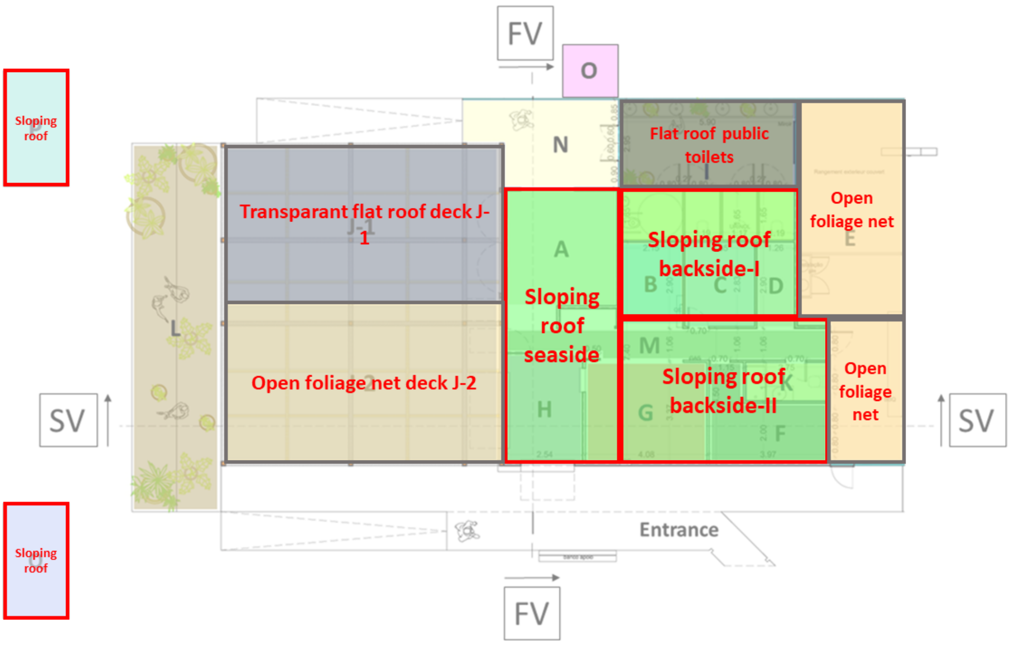


Figure 3.4: Blueprint of the top view of Irmão with the corresponding roof sections.

Looking at the front view of the restaurant in figure 3.6, it can be seen that the public toilet on the left of the building is just outside the restaurant area. The reason for this is that Irmão is obligated to have a public toilet for the whole beach area in front of Irmão. The same applies to the shower, which is also outside the restaurant.

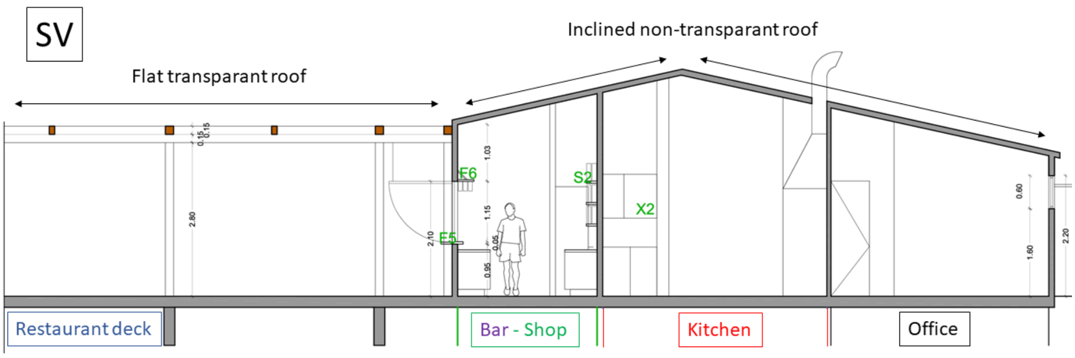


Figure 3.5: Blueprint of the side view of Irmão.

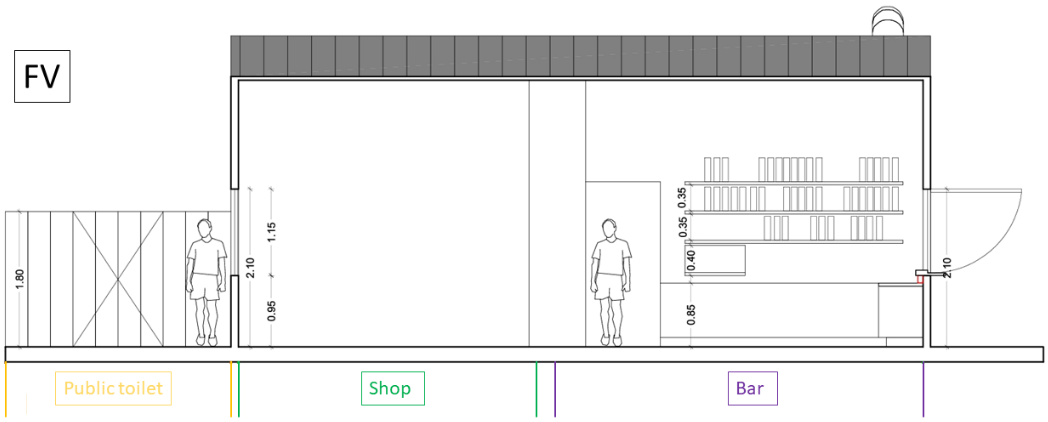


Figure 3.6: Blueprint of the front view of Irmão.

3.6. Construction materials

The restaurant is constructed of various materials. The majority of the construction consists of wood. During the growth of the trees, which were eventually used to build the restaurant, CO_2 is extracted from the atmosphere. The amount of CO_2 that is extracted, depends on the type of tree (Lamlom and Savidge, 2003). It is assumed that the wood used for the construction is from the *Pinus Pinaster*, also known as the Portuguese maritime pine. This assumption is made as it is one of the most common trees in Portugal and in the vicinity of Irmão (Nunes et al., 2019). (dos Santos Viana et al., 2018) states that the carbon content in the *Pinus Pinaster* is 48.8%.

$$CO_2 \leftrightarrow C + O_2 \tag{3.1}$$

Taking the molasses into account, 3.67 kg CO_2 is needed for 1 kg C. Assuming that *Pinus Pinaster* consists of 48.8% wood, 1.79 kg CO_2 is extracted from the atmosphere per kg wood.

3.7. Walking path

Irmão is located in the dunes and the distance between the parking area and Irmão is around 200 meter. To walk from the parking lot to Irmão, a wooden walkway is constructed. This is done to protect the dunes from people who would otherwise walk through the vegetation. The wooden walkway can be seen in figure 3.7 and figure 3.8. In figure 3.7, it can be noticed that the walking path consist of three straight parts. Part C-1 is 42 meter long, part C-2 is 80 meter long and part three has a length of 24 meter. The walking path is made of wood and has a width of 1.3 meter.

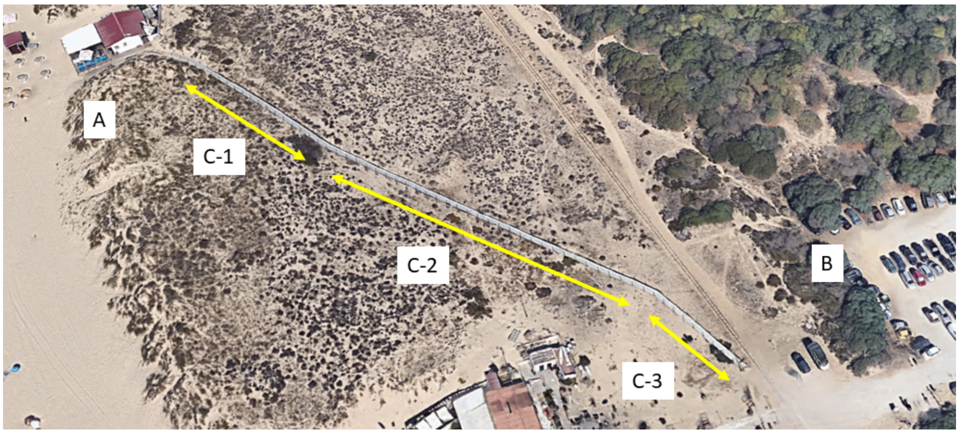


Figure 3.7: Walking path between parking area and Irmão. A = Irmão, B = Parking area, C-1 = Section 1 walking path, C-2 = Section 2 walking path, C-3 = Section 3 walking path.

Figure 3.8: Walking path between parking area and Irmão.

4

Analysis of the environmental situation

After defining the goal of the study and explaining what is in the scope of the study in chapter 1, the surrounding environment of Irmão is looked at. In order to assess the extent to which the processes at Irmão can be made more sustainable, it is necessary to clearly identify the natural resources near Irmão which could be exploited if needed. Therefore, a literature study is conducted to gain a deeper understanding of the environmental conditions at Costa da Caparica.

Section 4.1 examines the climate of Portugal. Then, in section 4.2, the environmental conditions related to the sun at the location of Irmão are examined. This includes the temperature, irradiance, sun height along with the sun hours. Thereafter, in section 4.3, the environmental conditions related to water are examined, meaning the ocean and the precipitation. Finally, section 4.4 discusses wind conditions around Costa da Caparica.

4.1. Climate

Despite not being located at the Mediterranean Sea, Portugal has a Mediterranean climate. One of the classifications for climate is the classification of Köppen. In the Köppen climate classification, Portugal can be divided into two classes. The Köppen climate type of Portugal can be seen in figure 4.1. These two classes are Csa and Csb, respectively the hot-summer Mediterranean and the warm-summer Mediterranean (Ritter, 2006). As shown in the figure, Costa da Caparica is right on the edge between these two climate types, but leaning towards the hot-summer Mediterranean. Regarding temperature, this means at least one month a year has an average temperature of 22 degrees Celsius or higher.

Figure 4.1: Köppen climate type Portugal (Adam Peterson, 2016)

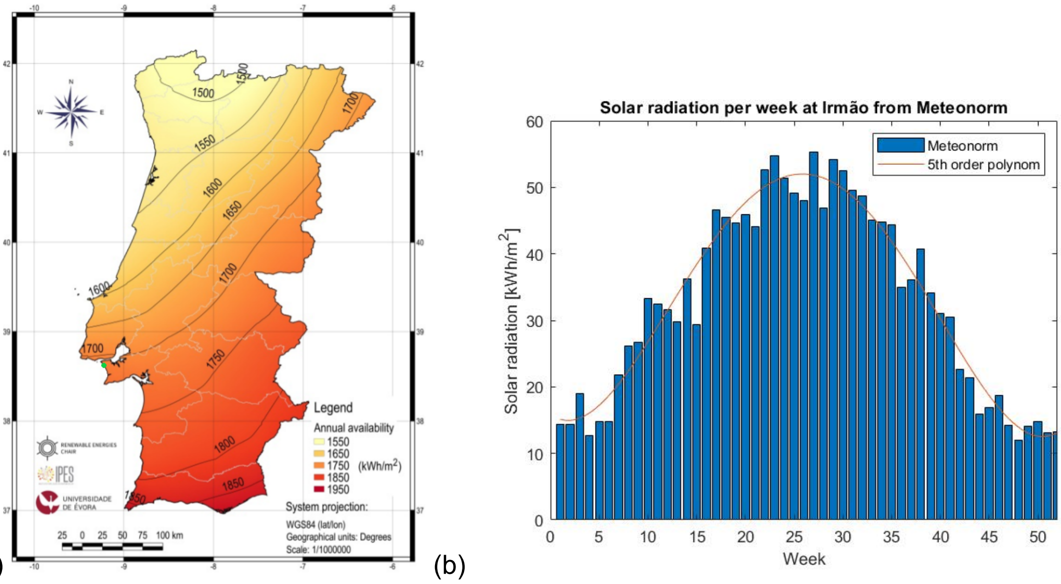
4.2. Solar

The following section will discuss different meteorological phenomena that are related to the sun. The different aspects on the sun that will be discussed are the temperature, irradiance, sun height and the sun hours.

4.2.1. Irradiance

Portugal's southern latitude leads to relatively high irradiance (W/m^2) compared to other parts of Europe. The irradiance together with the time this irradiance take place, lead to the solar radiation (Wh/m^2). The solar radiation is proportional to the amount of electrical energy that can be generated during a given time. Figure 4.2 (a) shows the distribution of solar radiation in Portugal, and it is clear that a more southerly position contributes positively to the annual amount of solar radiation. In this figure, Irmão is indicated by the green dot. The annual solar radiation is said to be 1709 kWh/m^2 (Cavanco et al., 2016).

The irradiance at a specific location also depends on the season. In the summer months, the solar radiation per day is many times higher than in the winter. This is mainly because the sun is at a larger angle from the horizon and the days are longer. It goes without saying that the radiation per day is larger when the sun shines more hours (h). That the irradiance is higher when the sun is at a larger angle relative to the horizon is due to the fact that the solar rays travel less distance through the atmosphere and therefore are less obstructed. Other factors like cloudiness also influence the irradiance.

(a)


(b)

Figure 4.2: (a) Solar radiation in Portugal (Cavanco et al., 2016. (b) Radiation in Costa da Caparica from Meteonorm

Figure 4.2 (b) is constructed with data extracted from Meteonorm. Meteonorm provides the irradiance in kW/m^2 over a certain hour. Since the given irradiance is for a whole hour, it can be said that when adding up these hourly data, the total solar radiation in kWh/m^2 is found. To verify whether the data from Meteonorm corresponds to the data found in the literature, all hourly irradiance for one year is summed. This summation comes down to a total solar radiation of 1709 kWh/m^2, which is similar to the values found in literature (Cavanco et al., 2016).

This graph is created by summing the irradiance corresponding to one week. The seasonal variability is clearly visible. In the summer months the solar radiation can go up to 50 kWh/m^2 per week, while in the winter months it only reaches 15 kWh/m^2 . To provide an average trend, a fitting was made with Matlab. This fitting has a R^2 value of 0.9532.

4.2.2. Sun height

As indicated in section 4.2.1, the irradiance depends, among other things, on the angle of the sun in relation to the horizon. This phenomenon is called the sun height. Meteonorm provides the angle that the sun makes relatively to the horizon for every hour of the year. Besides the influence the sun height has on the amount of irradiance on a solar panel, it can be also used to determine the amount of hours panels are blocked by surrounding obstacles.The graph in figure 4.3 is constructed by extracting all the highest angles the sun makes during the year at a given day.

One can see that there is a large difference in solar angle between the summer and winter. At its largest maximum heights, the sun is at an angle of 74.7 degrees which is at the 21^{st} of June. The sun is at its lowest maximum height at the 21^{st} of December, at an angel of 27.9 degrees.

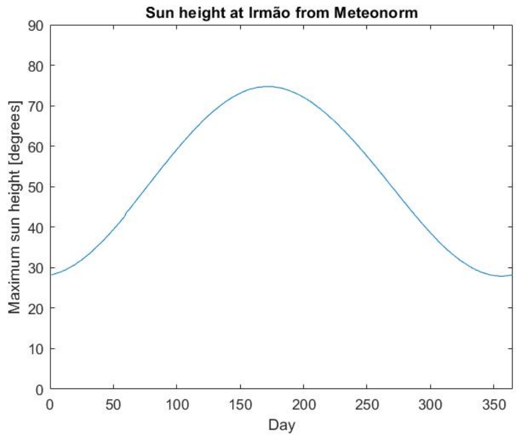
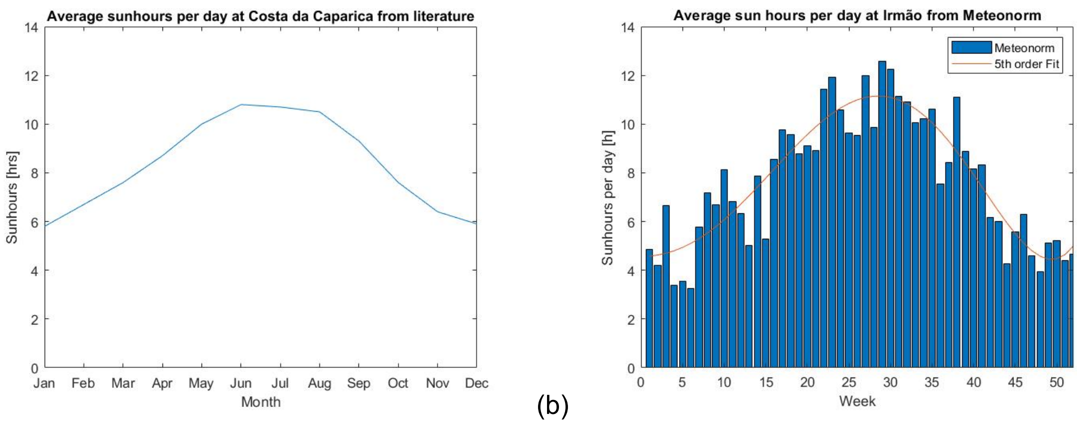


Figure 4.3: Sun height in degrees at the location of Irmão.

4.2.3. Sun hours

For the average amount of sun hours in Costa da Caparica per month, data found in literature is shown in figure 4.4 (a). The amount of sun hours is the total hours of perfect sunlight during a day and is therefore affected by the cloudiness. A significant difference is notable between the summer and winter months. With May, June, July and August all having 10 or more sun hours a day on average, June stands out with 10.8 hours. Only January and December have less than 6 hours of sun every day, with 5.8 hours for the month December being the lowest.



(a) (b)

Figure 4.4: (a) Sun hours Costa da Caparica (Climate-Data, 2021). (b) Sun hours at Costa da Caparica retrieved from Meteonorm.

From Meteonorm, the number of minutes of sunshine per given hour was obtained. Next, all hourly data for the same day was added up to obtain the number of minutes of sunshine per day and then converted into hours of sunshine per day. With this daily sunshine, the average sunshine per day for a whole week was then calculated by adding up the hours per day for the same week and dividing by the number of days in a week. This daily average for a week is presented in figure 4.4 (b). To compare the data from Meteonorm to the data from literature, a 5^{th} order polynomial was constructed as a fitting. The fitting has a R^2 error of 0.8113 and can therefore be considered highly correlative. The fitting constructed in Matlab is similar to the data from literature and therefore one can conclude that the data from Meteonorm is usable.

4.2.4. Temperature

In figure 4.5 (a), the average, maximum and minimum temperature per month are given (Climate-Data, 2021). As shown, the warmest month is August with an average of 21.9 °C and January is the coldest month with 11.8 °C on average. Therefore, the difference between the coldest and the warmest month in Costa da Caparica is 10.1 °C, as found in literature.

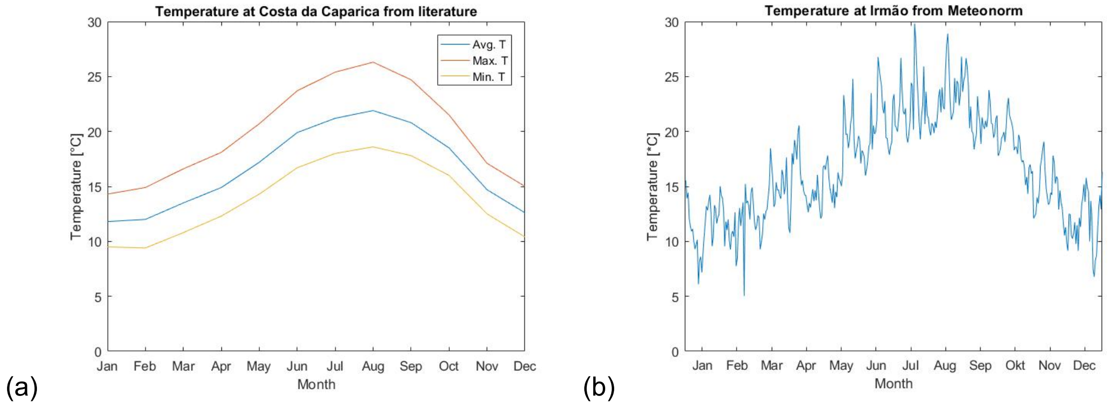


Figure 4.5: (a) Temperature Costa da Caparica (Climate-Data, 2021). (b) Temperature Costa da Caparica retrieved from Meteonorm.

From Meteonorm the temperature per hour is retrieved and plotted. This is shown in figure 4.5 (b). The graph was created by adding the hourly data per day to form an average temperature per day. One can clearly see that the data from Meteonorm corresponds to the data from literature except for a few days, in which the data form Meteonorm exceeds the data from literature. Meteonorm showed a similar highest temperature as in the literature around August as well as the coolest month being January.

4.3. Water

Besides the sun, the water around Costa da Caprica also is a natural resource which should be investigated. The following chapter discusses all the phenomena related to water.

4.3.1. Precipitation

Figure 4.6 (a) shows the monthly precipitation in Costa da Caprica that was retrieved from literature (Climate-Data, 2021). The Mediterranean climate is known for its dry summers and relatively wet winters. This fact can also be derived from figure 4.6 (a), while the precipitation in the wettest month is 87 mm and in the dryest month 3 mm, in November and July respectively. This accounts for the large difference of 84 mm between these months, with 27 times as much precipitation in November as in July.

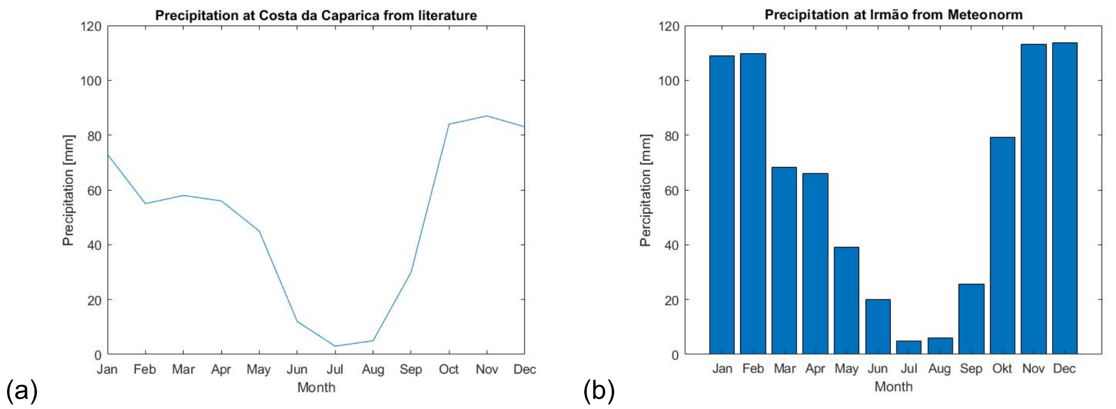


Figure 4.6: (a) Precipitation Costa da Caparica from literature (Climate-Data, 2021). (b) Precipitation at Costa da Caparica retrieved from Meteonorm.

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Figure 4.6 (b) represents the data retrieved from Meteonorm. The large deviation in precipitation between the summer and winter months is clearly visible. To obtain this graph, all precipitation fallen in one particular month was combined and showed in a bar plot. Comparing the graphs it is shown that the data from Meteonorm is slightly higher than the averaged climate but had the same shape.

4.3.2. The ocean

Costa da Caparica is adjacent to the Atlantic ocean to the west. This ensures that the winters are a bit warmer and the summers cooler than the inlands of Portugal. The average, minimum and maximum temperature of the Atlantic ocean water at the Costa da Caparica can be seen in figure 4.7 (a) and averages 16.8 °C. There is still quite the difference throughout the year, as the highest average water temperature is 18.9 °C and the lowest 14.5 °C, in respectively September and February.

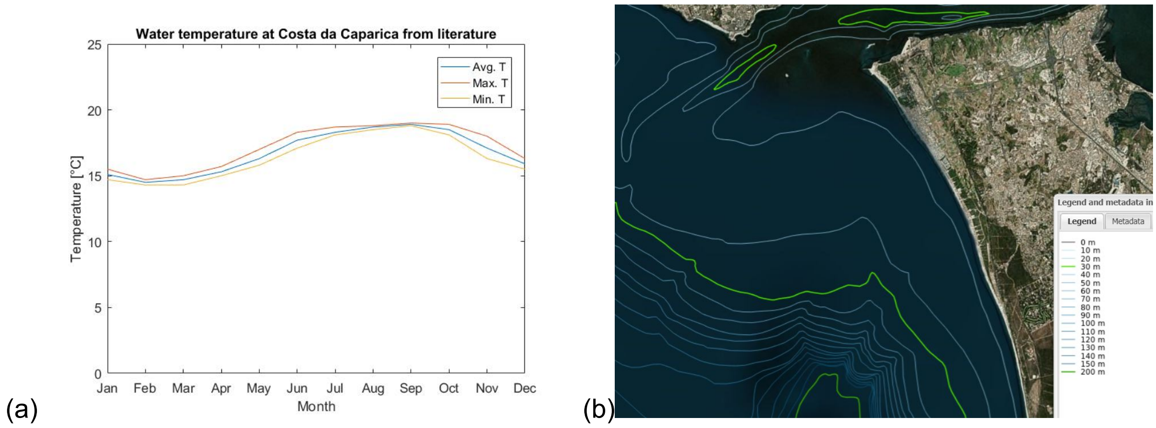


Figure 4.7: (a) Water temperature Costa da Caprica (Climate-Data, 2021). (b) Bathymetry of the coast of Costa da Caparica (WebGIS Portugal, 2015)

To have an idea on what the depth of the ocean water surrounding Costa da Caprica is, the bathymetry is given in figure 4.7 (b). In this figure the different submerge surface depths can be distinguished. The points with equal elevation are joined to make a bathymetryc line.

4.4. Wind

Figure 4.8 (a) shows the average wind speed per month as found in literature (World Weather Online, 2021). As there was no historical data available from Costa da Caparica, the data is taken from Lisbon. The average wind speed during the whole year is 5.0 km/h.

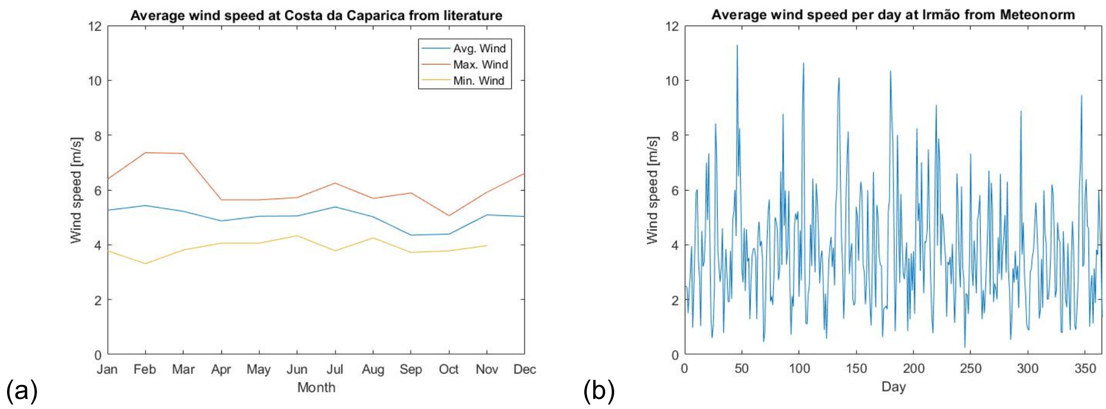


Figure 4.8: (a) Wind speed Lisbon from literature(World Weather Online, 2021). (b) Wind speed at Costa da Caparica retrieved from Meteonorm.

From figure 4.8 (a), it can be seen that the average wind speed is higher in winter and relatively lower in fall. The highest wind speeds are experienced in February and the lowest in September. Figure 4.8 (b) represents a graph constructed with data from Meteonorm. Meteonorm provides the hourly wind speeds. These hourly wind speeds are combined to derive the daily averages. Not only the wind speed averages are relevant, but also the maximum wind speeds. To give a clear overview of the monthly wind speeds, a box-plot is created in Matlab and presented in figure 4.9.

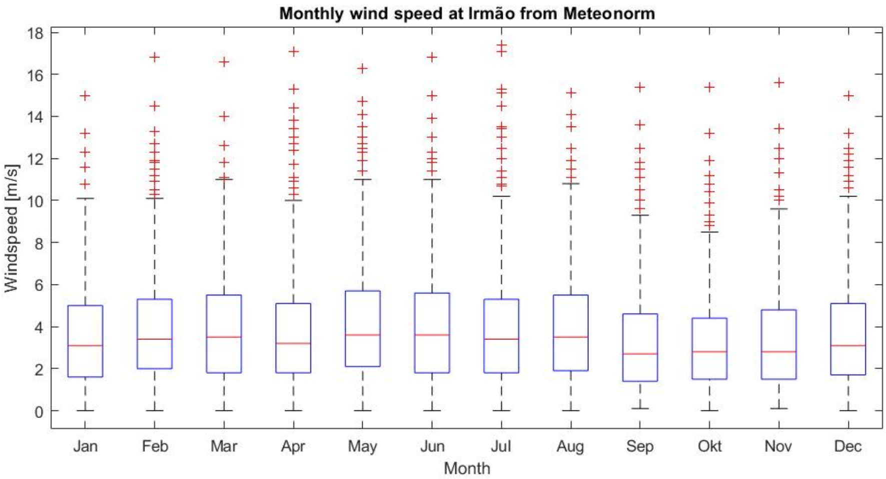
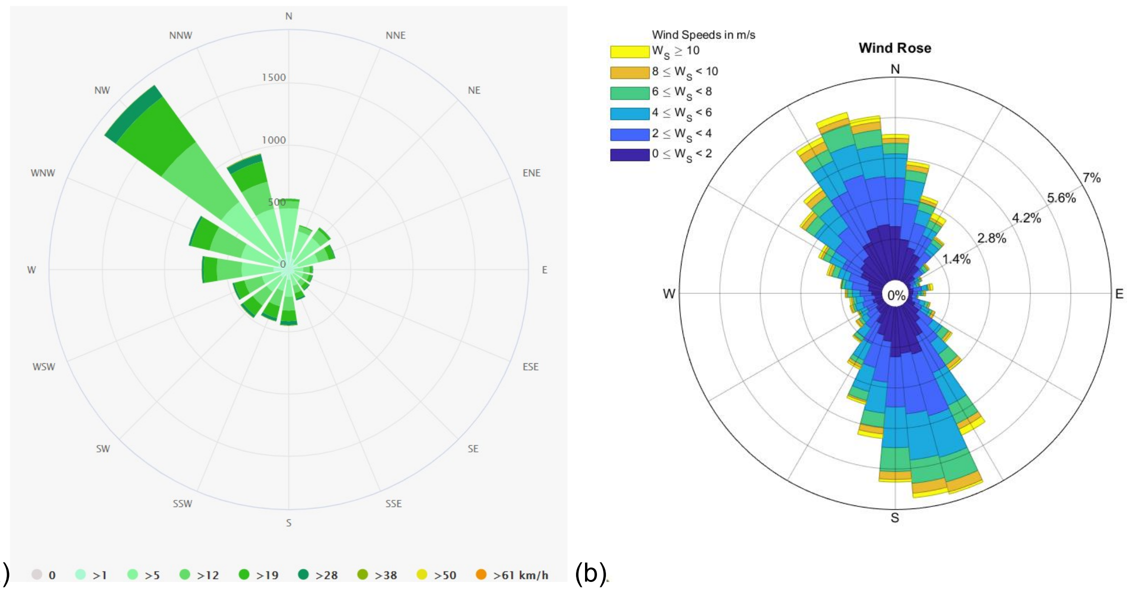


Figure 4.9: Boxplot of the wind speed at Costa da Caparica.

One can see that the median of the wind speed per month is between 3 and 4 m/s. The upper quartile reaches up to around 5 and 6 m/s. The monthly maxima are indicated by the red crosses. The maximum wind speed is close to 17 m/s. A small seasonal change in wind speed is seen throughout the year. The fall experiences relatively lower wind speeds while in the spring the wind speeds are higher.

4.4.1. Wind direction

Another important factor related to wind is its direction. Figure 4.10 (a) shows the most common direction of the wind as found in literature presented in a wind rose. From the figure one can see that the most common wind direction is wind coming from the North West.

(a)


(b)

Figure 4.10: (a) Wind rose at Costa da Caparica (Meteoblue, 2021). (b) Wind direction at Costa da Caparica from Meteonorm.

Figure 4.10 (b) shows the direction from the wind and its velocity as retrieved from Meteonorm. The plot was created using a Matlab code found online (Pereira, 2021). Strong differences between the data obtained from literature and the data from Meteonorm are observed. This can be attributed to the fact that the Meteonorm data is an interpolation between the four weather stations in the area and that wind has a strong locational dependency. Therefore it is chosen not to use the Meteonorm data.

5
Cover model

Since this study takes place during a limited period, it is required to make estimates of the energy consumption, water consumption and waste production during a period in which the consumption is unknown. This is done by translating the monitored data from January until September and conducted measurements, taken in September and October, to the rest of the year. The data that will be used relates to the occupancy rate of Irmão because the production of waste and the consumption of energy and water depends on the amount of guests Irmão will host. Therefore, section 5.1 provides insight in the monitored occupancy rate of Irmão. Hereafter, the measured data gathered will be expanded to the expected occupancy rate throughout the year in section 5.2.

5.1. Monitored occupancy rate

As mentioned before, the number of guests present at Irmão influences the water and energy consumption and the amount of waste produces, i.e. there is a strong correlation between these processes and the occupancy rate (T. Degermann, personal communication, September, 2021). To gather information about the occupancy rate of Irmão, the number of covers is used. A cover is known as a closing bill of an order, this can be one drink at the beach or a whole diner. On average it can be said that one cover equals 2 or 3 guests (T. Degermann, personal communication, September, 2021). In contrast to the number of guests, the exact number of covers is being monitored. Therefore, the number of covers is used during the regression and translation of the water consumption, energy consumption and for the waste production. Figure 5.1 presents the data of the monitored number of weekly covers of 2021.

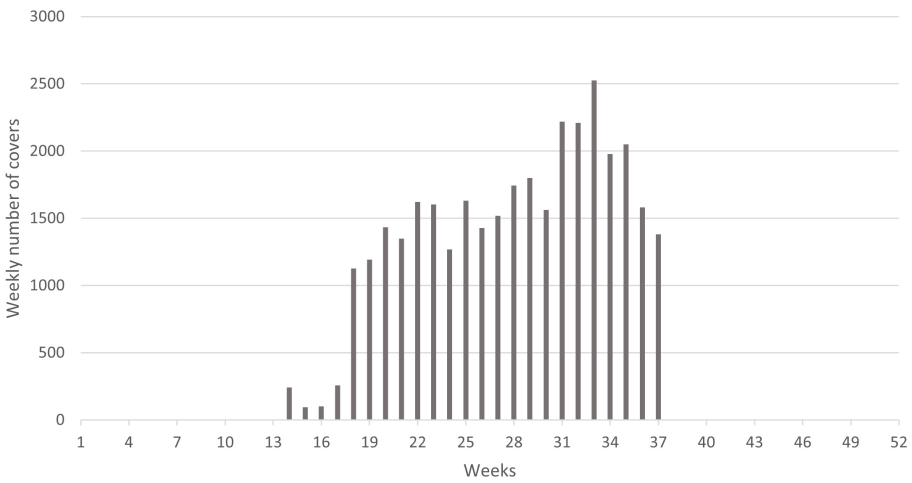


Figure 5.1: Monitored weekly covers of Irmão throughout 2021.

As can be seen in this figure, the measured data represents cover information for 46% of the number of weeks in a year. To have a clear overview of the waste production and the consumption of energy and water, information is required for the rest of the year. The monitored number of weekly covers in 2021 must therefore be expanded to the rest of the year.

5.2. Expected occupancy rate

As stated, the relation that is obtained during the regression, can applied to the expected number of covers throughout a year. These expected number of cover throughout an average year is the result of a market study that is conducted by the owners of Irmão. The amount of covers are based on a number of factors, namely vacation periods in Europe, air temperature, precipitation, number of sun hours a day and data from comparable restaurants (T. Degermann, personal communication, September, 2021). Figure 5.2 presents these estimates.

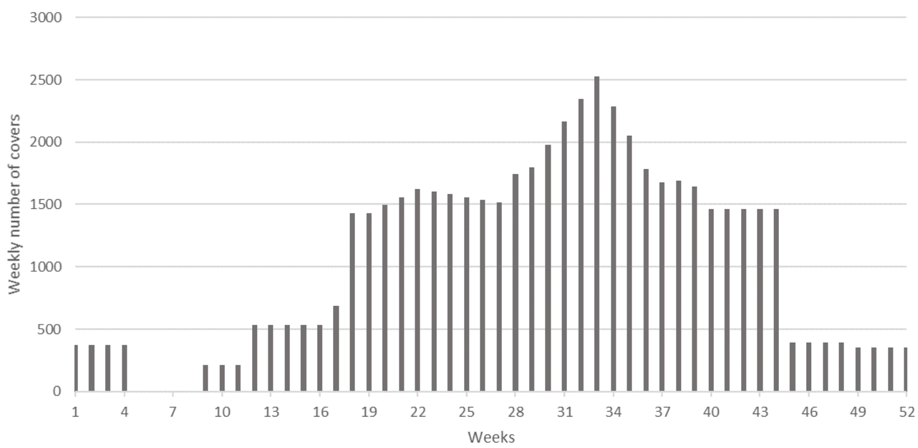


Figure 5.2: Expected number of weekly covers throughout a year.

The figure displays several jumps in the course of the data. Starting with an abrupt decrease from about 400 covers per week to zero at the end of January (week 5), the reason for this is that Irmão will be closed during this period. Irmão opens its deck again in week 9, but not yet the seats at the beach, hence the small jump back up. During the period from week 9 to week 17, there is quite a lot of rain and little sun shine at Costa de Caprica, but from the beginning of May the amount of sun hours starts to rise (see figure 4.4), as well as the temperature (see figure 4.5) and the amount of precipitation decreases significantly (see figure 4.6). Hence, Irmão is also reopening the spots on the beach from the beginning of May, that is why a jump in the number of covers is predicted in week 18. From the beginning of May till the end of October, the weather is good and thus Irmão receives a lot of customers. In figure 5.1 another peak can be seen the beginning of July till the end of August, since that is when summer holidays take place. Furthermore, the temperature is at its highest during these months and the amount of sun hours is at the maximum for Costa da Caparica see figure 4.5 and figure 4.4. At the end of October a jump back down can be seen, as the Irmão closes its beach seats again due to the increase in precipitation and the decrease in temperature and sunshine hours.

In section 6.2 and section 12.3 the execution of the polynomial regression between the number of covers and water & energy consumption is provided.

II
Water system

6
Water system analysis

This chapter describes the analysis of the current state of the water system of Irmão. In section 6.1 the analysis of the sources used by the restaurant is presented. Followed by the analysis of total annual water flows of Irmão, presented in 6.2. Finally, a summary is provided in section 6.3.

6.1. Water source

Irmão uses two types of sources to meet its water demand, namely a ground water borehole that is constructed in the dunes underneath the restaurant and a connection to the public water grid.

6.1.1. Groundwater borehole

In conversation with one of the owners T. Degermann, the following information was obtained regarding one of the sources used by Irmão. From an aquifer, water is is extracted through a pipe that extends nine metres into the ground and is connected to a jet pump with capacity of 60 l/min. This pump is connected to a pressure decay meter, which causes the pump to be activated when the pressure on the outgoing pipe, connected from the pump to the devices, decreases due to water consumption of the devices (T. Degermann, personal communication, September, 2021). From the middle of August until the middle of September, there were problems with the pump. As a result, the pump, and therefore the borehole, was out of order during this period. It turned out that there was a problem with the connection between the pump and the pipe. Causing the pressure to become unstable and the pump to stop regularly. However, it took the owners of the restaurant a month to find the problem and it was decided to switch completely to water from the grid during this period (T. Degermann, personal communication, September, 2021).

6.1.2. Public water grid

The water consumed from the public water grid is supplied by a company called Servicos Municipalizados de Agua e Saneamentos (SMAS). SMAS is responsible for drinking water supply, waste water collection and treatment, and drainage of rainwater of the council of Almada. Annually, they extract 17 500 000 m^3 of water from the Tejo-Sado aquifer. Goundwater is the only source used to meet this water demand. (SMAS, 2016)

Sustainability and the preservation of natural resources is one of SMAS' main goals. This is done by optimising the efficiency of (waste)water treatment as well as detect leakages and losses by performing Measurement and Control Zone studies that can detect and locate leakages. Furthermore, studies are performed on ways to preserve the aquifer by proper rejection of effluent. They build and incorporated state of the art equipment to process wastewater in different WWTP that are self sufficient for 27% in terms of energy. This energy is generated from produced bio-gas and from photo-voltaic solar system. (SMAS, 2018). Over the years, SMAS has won a considerable number of awards and distinctions, therefore the public water supply company is considered relatively sustainable (SMAS, 2018).

To quantify the footprint of the water used at the restaurant, the study of Pombo et al. is used (Pombo et al., 2018). This study first presents the energy required for the urban water cycle of a water company (AdRA) located 100 km north of Lisbon, followed by the amount of CO_2 that is emitted during the production energy. The study presents that AdRA uses 0.46 kWh for all different stages of the water cycle of one cubic metre of clean water (Pombo et al., 2018). The cycle includes the abstraction, treatment and distribution of potable water (the supply system), and the drainage treatment and rejection of treated wastewater (the drainage system) (Pombo et al., 2018). As will be further discussed in Chapter IV, on average in Portugal 241 g of CO_2 are produced for the generation of 1kWh. This means that 0.11 kg CO_2 is emitted for the production and processing of 1 m^3 water from the public grid. However, three things should be noted about this calculation. First, Irmão consumes water produced by a company other than AdRA, so it is likely that a different amount of energy is used; second, the share of energy suppliers to the Caparica water company (SMAS) is unknown, and therefore the average of Portugal is used for CO_2 emissions per kWh produced; third, the CO_2 emission due to the necessity to empty the wastewater storage tank and discharge it into the sewer, which is done by tractor, is not included in the CO_2 per m^3 of water. This may lead to some bias, but for the purpose of this study it is assumed that this method provides sufficient result.

6.2. Water use

This section aims to provide an overview of the different water devices present at Irmão and their consumption. Furthermore, the water consumption of the past year is identified and an estimate of the pattern of water consumption through an average year is presented.

The first step in the analysis of the water system is to identify which water devices are present and measure their flow rate. The location of all the water devices at Irmão is presented in figure 6.1. The flow rates are measured by letting water flow from the tap for a certain length of time and collecting it in a bucket, then measuring the volume of this water, the flow rate is then known. For each tap in Irmão this measurement was carried out three times, the results of these measurements are shown in Appendix B.1. In table 6.1, the averages of the three measurements are shown per tap. Also the water use per flush of the toilets (5,6 l/flush; Roca) and of the washing machine (3 l/cycle; True-Inox) have been obtained from the technical specifications according to the vendor's website.

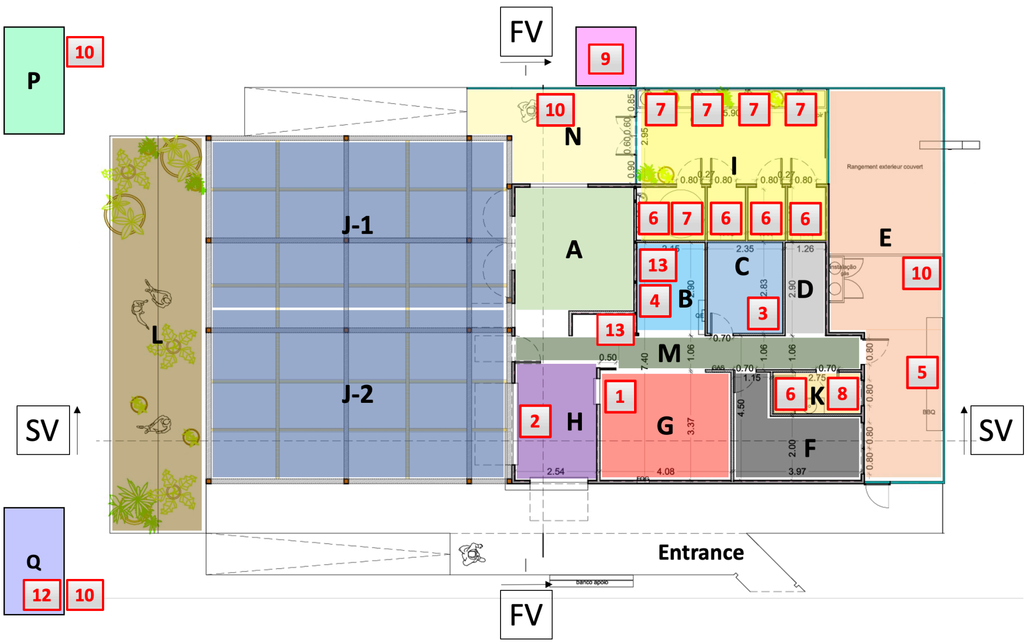


Figure 6.1: Water consuming devices of Irmão. (1) Tap kitchen; (2) Tap bar; (3) Tap pizza area; (4) Tap dishes area; (5) Tap at the back; (6) Toilets; (7) Toilet taps; (8) Tap employee toilet; (9) shower; (10) Hose; (12) Surf shack; (13) Drinking water machine; (14) Dishwasher.

Table 6.1: Average of three measurements conducted to measure the flow rate of the taps, the hose and the shower at Irmão.

Device number	Device	Flow rate [l/min]
1	Tap kitchen	7.5
2	Tap bar	6.9
3	Tap pizza area	13.6
4	Tap dishes area	9.3
5	Tap at the back	7.3
7	Toilet taps	6.9
8	Tap employee toilet	2.8
9	Shower	13.4
10	Hose	15.7

As mentioned before, Irmão receives water from two sources, namely the public water grid and the borehole. The borehole is used to supply water for the toilets, the toilet taps, the shower, the hoses and the surf shack. Water from the public water grid is used to supply the tap in the kitchen, tap at the bar, tap in the pizza area, tap in the dishes area, tap at the back, dishwasher and the drinking water machine. In the course of this report, for ease of reference, the taps just mentioned will be merged and called taps Irmão. A schematic overview of the water flows is given in figure 6.2.

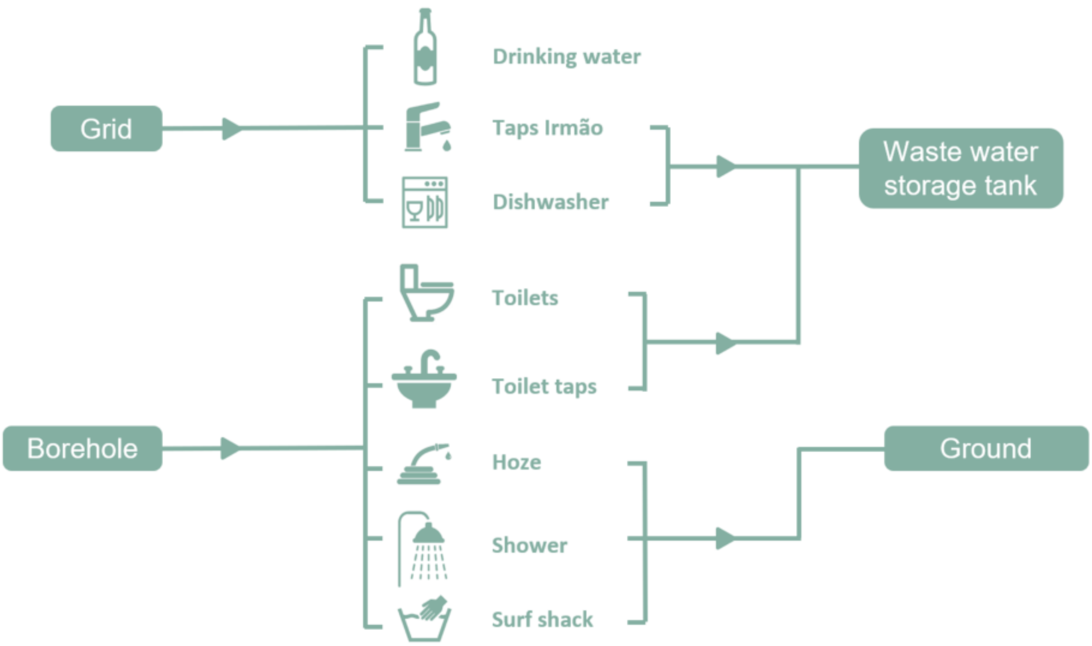
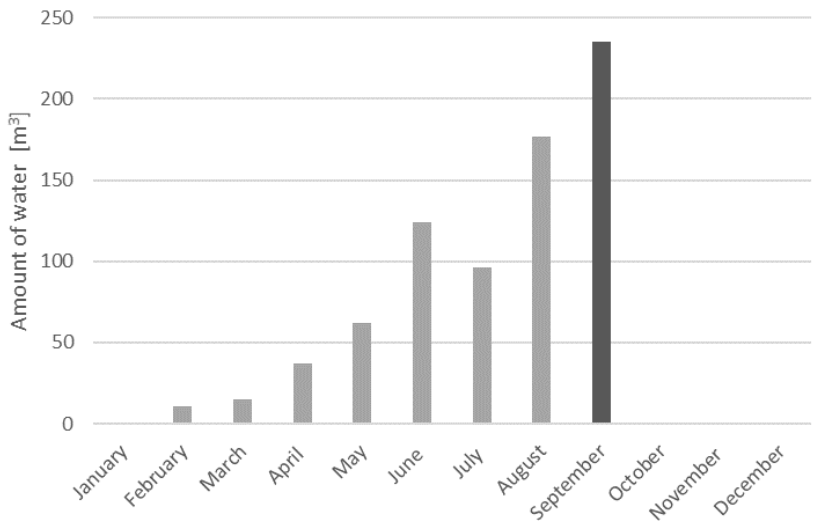


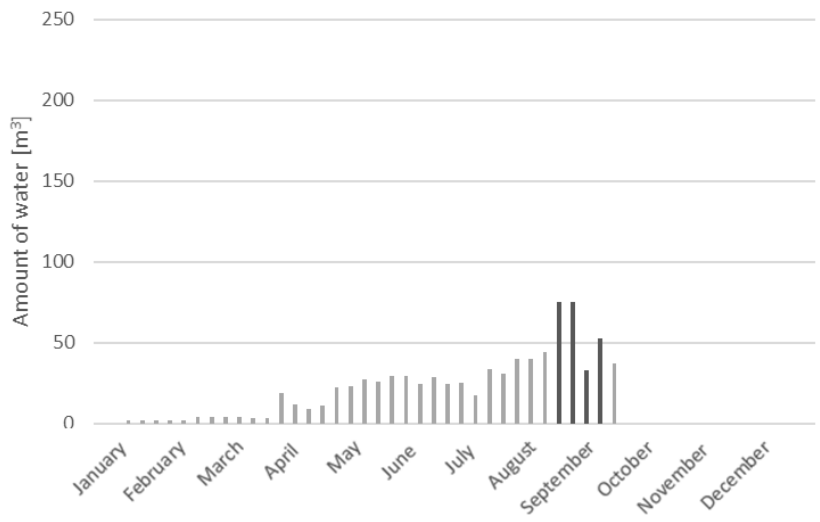
Figure 6.2: Systematic display of the current water infrastructure.

6.2.1. Water obtained from public water grid

As explained in chapter 5 the water consumption of Irmão for an average year is based on the relation between the exact number of covers and the amount of water received from the public water grid. A covers is known a closing bill, this can be a drink at the beach or the bill of a diner. During the period June until September there is data available on the monthly water consumption in the form of monthly water bills obtained from the owners of Irmão. The monthly water consumption is presented in figure 6.3(a) and can also be found in appendix B.3. Since the pump in the borehole was not functional during the whole month of September, this month does not give a representative impression on how the situation generally looks like, as all the water used in the restaurant during this period was received from the grid. Therefore, the bar indicating September in figure 6.3(a) is presented in a different colour. However, this monthly data does not provide an insight into consumption in the shorter term, which is why it is interesting to translate the monthly data into weekly data, so that peak consumption can be analysed. This translation is based on the ratio of the number of weekly covers in a given month. In addition, a basic water volume of 8 m^3 per week is estimated in case there is at least one cover. This value is based on the assumption that with at least one cover, 6,5 m^3 of water is used by the taps in Irmão, for preparing meals and cleaning the restaurant. In addition 1 m^3 of water for the dishwasher and 0,5 m^3as drinking water for the staff. In case of no covers, i.e. when Irmão is closed, the basic consumption is estimated at 3,25 m^3. This value is based on the amount of water consumed during the months of February and March of 2021, when Irmão was closed and consumed an average of 3,25 m^3 per week for tasks such as maintenance and cleaning. The result of the translation of the monthly data to the weekly data is presented in figure 6.3(b) and can also be found in appendix B.3.



(a)



(b)

Figure 6.3: Data of monthly water consumption from public water grid (a), obtained from the owner in the form of monthly water bills. The monthly data has been translated into weekly data (b), this is done to be able to analyse peak consumption. The bars having a darker colour present the month in which the pump of borehole was not working and therefore gives a distorted result.

As explained in chapter 5, a regression can be made in order to find the relation between the amount of water received and the number of covers in the same period. The result of this regression is presented in figure 6.4. It shows a first order and a second order regression.

From a mathematical and physical point of view, it seems that the second-order regression gives a better reflection of the situation. What is noticed is that the R^2 of the second order polynomial (R^2 = 0,8621) is slightly higher than the R^2 of the linear one (R^2 = 0,8343), which implies that the polynomial line fits the data points better. What is even more important is the explanation from a physical point of view. The second order polynomial shows a slight increase in water consumption as the number of covers increases. This can be expected due to the following factors. Firstly, it can be noted that the number of covers increases in the summer months, with sunnier weather and higher temperatures. Warmer weather leads to people drinking more and washing their hands more often. Because of people drinking more, an increase in the amount of dishes that must be cleaned is expected. Based on this reasoning, the relationship obtained by performing the second order polynomial regression used in the course of this study.

Applying this second order relation to the expected number of weekly covers, as explained in chapter 5, the expected weekly amount of water received from the grid is generated. The result is presented in figure 6.5. The figure shows that a peak of 44 m^3 is expected during week 33 in August. The exact outcome of this method is provided in appendix B.3. When summing up the expected weekly consumption, a yearly amount of 1108 m^3 is obtained. This equates to an annual cost of €4.400 and an emission of 122 kg CO_2 per year.

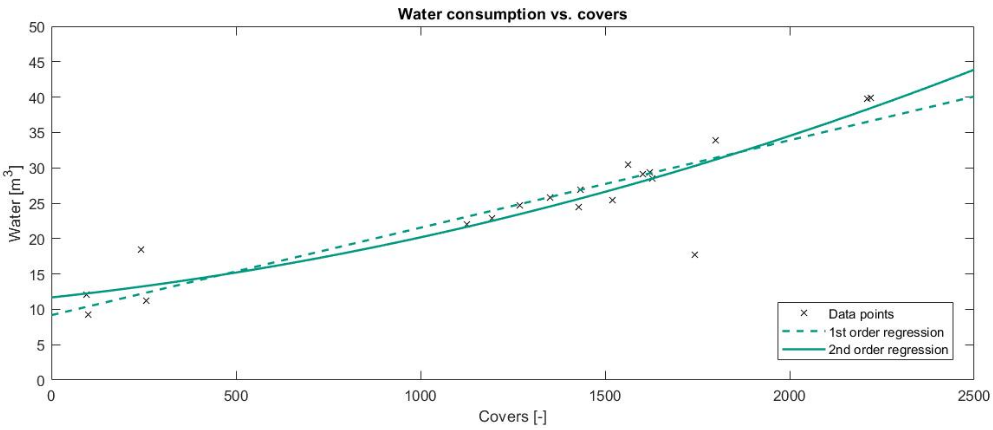


Figure 6.4: Result of second order polynomial regression between number of monitored weekly covers and the weekly amount of water obtained from the grid.

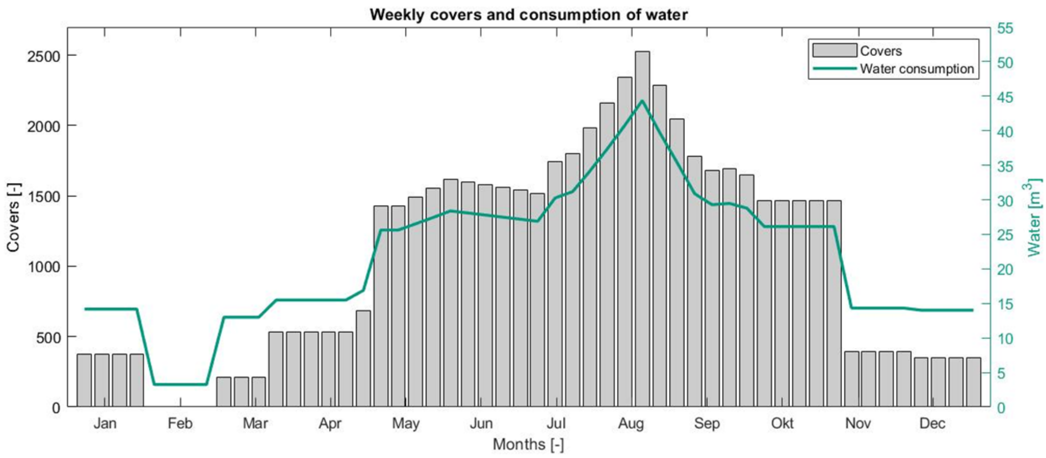


Figure 6.5: Weekly water consumption from water grid estimate, based on results of second order polynomial regression between monitored weekly number of covers and weekly amount of water obtained from the grid.

The ratio between the water usage that is received from the grid is based on two assumptions. First of all is assumed that for every two or three persons the dishwasher must run one time, keeping in mind that one covers is more or less equal to two or three persons. The dishwasher uses 3 liter per use (MAQUINA, 2021), therefore it is assumed that the dishwasher consumes 3 liter of water for each cover. It is expected that throughout the year there will be almost 55.000 covers, this result in a water consumption of 164 m^3/year for the dishwasher. The second assumption contains the amount of water a person drinks on average. It is assumed that a guest on average drinks 0.5 liters of water during their stay and an employee drinks 1 liter during their stay. During a week there will be at least 50 working shifts of an employee. This results in a yearly amount of 85 m^3 a year. Finally, the amount water that will be used by the taps is then the total yearly amount of water that expected to be received minus the drinking water part and the water for the dishwasher. Resulting in 859 m^3 of water per year. For clarity, the enumeration is shown below. Also, the percentage distribution can be seen in Figure 6.6.

- Drinking water machine (85 m^3/year)
- Dishwasher (164 m^3/year)
- Taps Irmão (859 m^3/year)

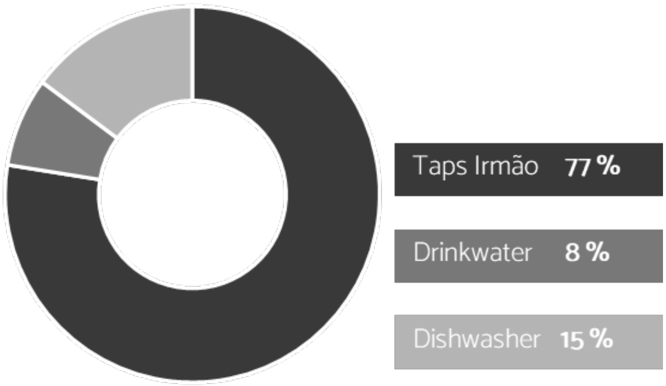


Figure 6.6: Water consumption ratio between the devices connected to the public grid.

6.2.2. Use of water obtained from borehole

As presented in the flow diagram in Figure 6.8, there are five devices supplied by water from the borehole, namely the toilets, taps in the toilet, the shower, the hose and the tap in the surf shack. Since the amount of water supplied from the borehole is not monitored, the amount of water withdrawal is estimated based on a number of founded assumptions and estimations. First of all, it is assumed that on average a person uses the toilet once during his or her stay in Irmão. In combination with the assumption that one cover on average equals 2.5 persons and that the toilet uses 5.6 litres per flush, the annual consumption of the toilets is estimated at 768 m^3. It is also assumed that this same number of people wash their hands for about 10 seconds at the toilet taps that use 6.9 l/min. This gives an annual consumption of 158 m^3. In consultation with the owner, the conclusion was drawn that the shower is on for an average of 30 minutes a day. As Irmão is open 6 days a week and the shower has a consumption of 13.4 l/min, it was determined that the shower uses 116 m^3 of water annually. Furthermore, it has been determined in consultation with the owner of the restaurant that an average of 250 litres per day is used to wash the wetsuits in the surf house. This comes down to an annual amount of 60 m^3.In consultation with the owner, it is estimated that the garden hose is used for an average of 20 minutes a day to water the plants and clean the restaurant. With a flow rate of 14.7 l/min, an annual consumption of 104 m^3 is expected. For clarity, the enumeration is shown below. Also, the percentage distribution can be seen in Figure 6.7. The exact list of expected water withdrawal throughout the year is presented in appendix B.3.

- Toilets (768 m^3/year)
- Toilet taps (158 m^3/year)
- hose (104 m^3/year)
- Shower (116 m^3/year)

- Surf shack (60 m^3/year)

Adding up the use of these five devices gives a value of 1205 m^3/yr. in order to pump this amount of water from the borehole, the pump with flow capacity of 60 l/min, must pump for 335 hours per year. Pumping for 335 hours with a power of 0.75 kW results in 250 kWh per year, which equals an emission of 60 kg CO_2.

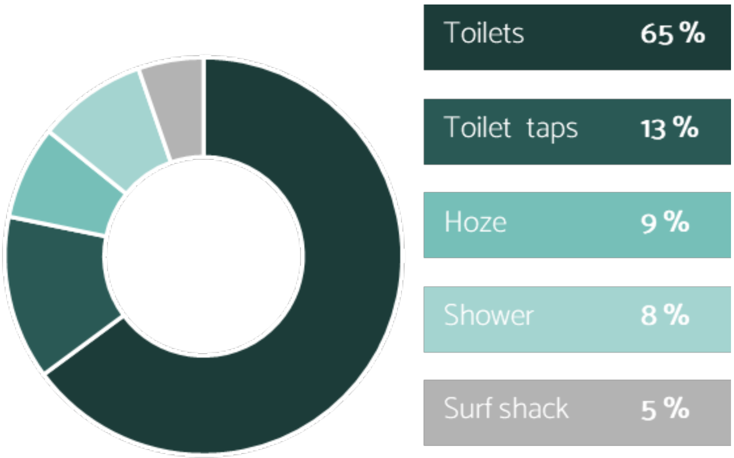


Figure 6.7: Water consumption ratio between the devices connected to the borehole.

The period,from 20/08/2021 until 20/09/2021 in which the borehole failed to supply water, is used to validate the model for estimating the water supply from the borehole. As mentioned earlier, all the water that was consumed by Irmão during this period originated from the grid. The relationship, resulting from the polynomial regression between the weekly coverage rate and the weekly amount of water received from the public grid, is used to estimate the amount of water in case the borehole did not work. In combination with the model that estimates the weekly water withdrawals from the borehole, it is determined whether the estimate is a realistic representation of the actual situation. Table 6.2 shows that the sum of the estimated amount om water from the grid and water from the borehole are on average overestimated by 7% compared to the actual situation. Looking at week 36, the estimates (57.4 m^3) seem to deviate from the actual amount of water obtained (33 m^3). The reason for this is unclear, what is notable is that the measured data of week 36 (33 m^3) is low for the amount of covers of that week (1582 covers), compared to the data of the past year. For this reason, it is assumed that the models provide a sufficient approximation of reality.

Table 6.2: Validation of the models for estimating the amount of grid water en borehole water during period that there was no supply of groundwater due to a pump being broken.

Weeks	Number of covers	Water received from grid (m^3)	Grid polynomial estimation (m^3)	Ground water withdrawal estimation (m^3)	Grid and groundwater estimates summed up
Week 34	1978	75	33.0	37.5	70.5
Week 35	2050	75	34.3	38.8	73.1
Week 36	1582	33	26.6	30.8	57.4
Week 37	1380	52	23.8	27.4	51.2
Total		**235**	117.6	134.5	**252.1**

The models in which the amount of water obtained annually from the grid and the amount of water extracted annually from the ground are used to determine Irmão's total annual water flows. The result is presented on the Sankey diagram in figure 6.8.

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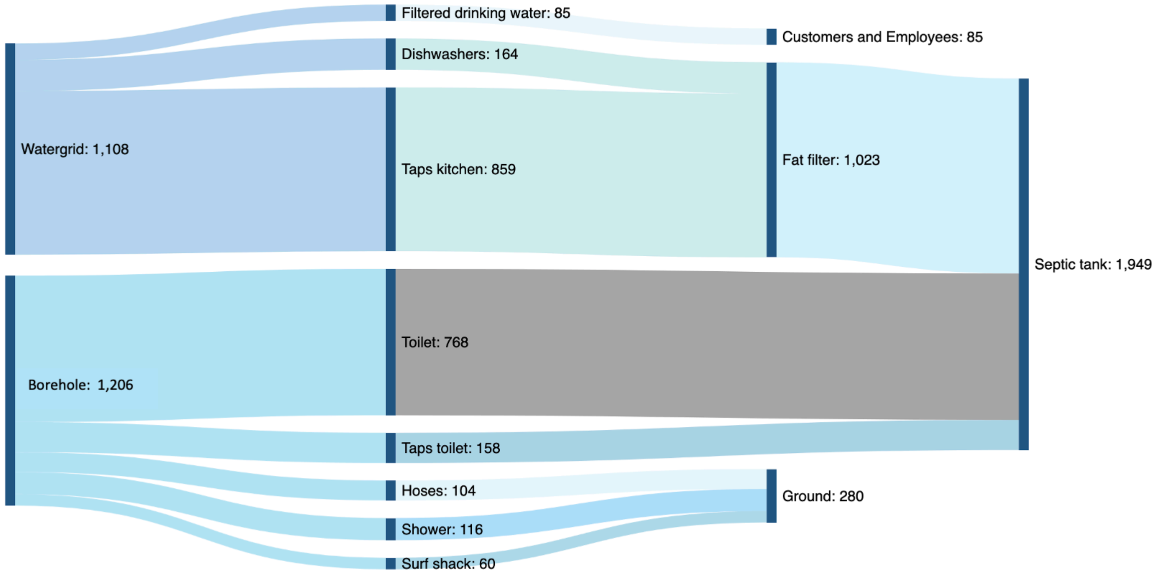

Figure 6.8: Sankey diagram containing the annual water flows at Irmão in m^3

6.2.3. Water drainage and sewage system

At present, all the water is discharged after being used once. The two drainage systems that are currently used, is the disposal into the ground and the disposal towards a waste water storage tank. The water from the hose, the shower and from the surf shack is being disposed into the ground. The wastewater from the other devices, as presented in the figure 6.8, is discharged into the tank. The water used in the kitchen is filtered by means of a fat filter, before it goes to the waste water storage tank. As figure 6.8 shows, 1949 m^3 of waste water flows into the storage tank annually. In addition, human waste is flushed into the tank by the toilets. The amount of human waste is calculated based on the assumption that on average a person deposits half a litre of urine when visiting the toilet, and on average 0.1 litre of faeces. Since the estimated annual toilet visits is 140.000, a total annual human waste volume of 62 m^3 per year is calculated. Leading to a total expected volume of 2010 m^3, that will be discharges into the waste water storage tank each year.

The waste water storage tank has a capacity of 5 m^3. On a busy day the tank is not big enough to store all the wastewater. Therefore, on busy days, it is possible that tank has to be emptied multiple times by a farmer who collects the waste water and discharges it in the public sewage system. The owners of Irmão try to start the day with an empty tank so it is often emptied even when it is not completely full. In consultation with the owners, it has been estimated that the tank is emptied when it contains a volume of 3.5 m^3, on average. The costs of emptying 2010 m^3 of waste water from the storage tank is €8.000 per year (T. Degermann, personal communication, October, 2021) . Assuming that the tank is emptied if 3.5 m^3 is present, it can be concluded that the tank is emptied approximately 575 times per year.

6.2.4. Regulations water system

There are a number of regulations concerning the use of water and its disposal. First, the regulations regarding the use will be discussed, followed by the regulations regarding the disposal of water. The most important regulation regards the quality of the drinking water. This is the water that people directly consume but also the water that people indirectly consume, i.e. water that is used to wash the dishes. To ensure that this water is of the right quality, it is tapped from the grid. Without a permit it is not allowed to use water from the borehole as drinking water. If Irmão wants to use the borehole as a source of drinking water in the future, the water will have to be filtered and its quality monitored by the government. be checked has to be filtered, to ensure the quality of the water. Furthermore, without the permit, Irmão is obliged to place signs that clearly state it is forbidden to drink water at places where the water comes straight from the borehole, for example at the shower and the taps in the toilet.

There are also regulations on the disposal of waste water. The most important one is that it is forbidden to let waste water flow into the dunes. This does not include, for example, water from the shower and from the hoses as this water stays very clean. However, this rule does apply to water from the toilets and contaminated water from the kitchen, which is why this waste water is collected in a waste water storage tank and then transported to the regular network. The regular network requires that the water from the kitchen first passes through a 'fat box'. Here, any fat present in the water from the kitchen is separated from the water before it can be disposed of.

6.3. Summary water system analysis Irmão

The analysis of the current water system showed that the restaurant uses water from two different sources, namely the public grid and the borehole. Monthly data of the amount of water obtained from the public grid is available from February to September 2021. In addition, the quantity of weekly covers is also available from this period. As described in chapter 5, by means of a regression, the relation between the water withdrawal and the number of covers can be obtained. This relationship was then used to obtain insight in the estimated yearly amount water that must be received from grid in an average year, shown in figure 6.5. According to these calculations, an estimated 1108 m^3 per year is obtained from the public grid at a price of €4.400 per year. SMAS, the company that supplies and processes the water, emits an estimated 122 kg CO_2 for cleaning this amount of water. The water obtained from the grid is used by the following devices:

- Drinking water machine (85 m^3/year)
- Dishwasher (164 m^3/year)
- Taps Irmão (859 m^3/year)

As can be seen, most of the grid water is used for the taps in Irmão. What stands out is that there are some taps with a remarkably high flow rate, for example the tap in the dish area with a flow rate of 9.3 l/min and the tap in the pizza place with a flow rate of 13.6 l/min. The complete list of measured flow rates can be found in Table 6.1.

The determination of the water consumption from the borehole is done in a different way, because there is no record of how much water is pumped from the borehole. However, it was possible to determine the water use from the borehole by making a number of borehole-founded assumptions and estimates. The results appear plausible when compared to literature and compared to the water bill of September. Due to a pump malfunction in the entire month of September 2021, it was not possible to use water from the borehole and all the water used came from the public grid. This led to the water bill from the grid being about twice as high in this month, similar to the findings received. According to the study, it is estimated that 1205 m^3 will be obtained from the borehole per year. Since the pump uses electricity to pump this amount of water, this also leads to some emissions, namely 60 kg CO_2 per year. The water withdrawn form the borehole is distributed among the devices in the following way:

- Toilets (768 m^3/year)
- Toilet taps (158 m^3/year)
- hose (104 m^3/year)
- Shower (116 m^3/year)
- Surf shack (60 m^3/year)

It can be noted that the toilets are the main consumers of water from the borehole. The five toilets currently use 5.6 litres per flush and are estimated to be used a total of approximately 140,000 times per year, leading to this high consumption.

In terms of waste water disposal, the analysis has shown that the current system is causing problems. This is because a 5 m^3 waste water storage tank is used, which receives 2010 m^3 of wastewater annually. If this tank overflows, it causes an unpleasant odour and damage to nature, which must be prevented. Therefore, a farmer comes daily, or often several times a day, to empty the storage tank and drain the wastewater into a sewer system. It is estimated that the tank has to be emptied 575 times a year, at a cost of €8.000 a year. Besides the fact that this emptying costs money, the farmer who comes by tractor emits CO_2 and other pollutants.

As far as the sustainability of the current system is concerned, it can be concluded that the annual emissions of the water system are negligible. However, it has become apparent that the current system uses a lot of water and is not frugal in its use of water. For example, no water is reused and there are a number of devices with a relatively high consumption. The follow-up of this study will focus more on reducing water use than on reducing emissions. However, reducing water use and reducing emissions often go hand in hand.

7
Water system design concepts

After analysing Irmão's current water situation in Chapter 6, the best areas for Irmão to become more sustainable in terms of water will be examined in this chapter. This will be done by listing different solutions per topic and assessing them according to different weighted criteria. First section 7.1 addresses the water source, then section in 7.2 ways to reduce the water demand are discussed and finally section 7.3 addresses the drainage system. Thereafter, concepts will be compiled based on the best solutions in section 7.4.

7.1. Water source

Annually, Irmão spends €4.400 on water from the grid. Although sustainability and conservation of natural resources is one of the main objectives of SMAS, the water supplier. SMAS emits about 122 kg of CO_2 to purify the water that Irmão receives from the grid. As mentioned in section 6.1, it is estimated that 0.46 kWh is used to in the water cycle one m^3 of water. Hence, it is useful to see if there are alternative sources that would allow Irmão to save money and become even more sustainable.

For this study, the desalination of seawater will be considered as an alternative source, since Irmão is located on the beach. Collecting rainwater, since the area where Irmão is located has a relatively high amount of precipitation throughout the year as can be seen in Chapter 4. Circularity will be compared, as the reuse of water is in line with the goal of making the beach club more sustainable. And finally, the borehole as a source will be compared with the other proposed sources.
In order to compare the different sources of water, a multi-criteria analysis is used (see Table 7.1), which is carried out as described in Chapter 2. Besides the 7 standard criteria, the analysis will also be conducted with one topic specific criteria, which is the potential of the source. The potential of the resource indicates whether the resource can meet Irmão's demand. It also takes into account how much water can be extracted from the resource without depleting it. In other words, whether the resource is self-renewing or finite.

Table 7.1: Multi-criteria analysis alternative water sources.

General criteria	**Weight**	Rainwater	Circularity	Desalination of sea water	borehole
Cost	5	3	4	1	4
Ease of implementation	3	3	3	1	5
Maintenance	3	2	5	1	3
Environmental impact	5	3	3	3	4
Esthetics	2	3	5	2	5
Lifetime	3	5	4	3	3
Topic specific criteria					
Potential of the source	5	1	3	5	4
Weighted total		**71**	**96**	**64**	**103**

Rainwater collection
Rainwater harvesting scores average on most of the criteria. But it falls well short on the topic specific criteria, ’Potential of the source’. This is due to the fact that Irmão’s demand for water and the supply of rainwater collection do not match. Since it is busy at Irmão in the sunny months and quiet in the rainy months, the demand for water is high in the sunny months and very low in the months with a lot of rainfall. A large storage tank would therefore be needed to ensure that rainwater is available during the dry and busy months. However, it would have to be so large that it is not realistic to implement. Rainwater collection can be done, for example, with gutters on the eaves. Which is estimated to cost about €5.000 to €10.000. This is a simple and robust construction, which is why it is estimated that it will last for a long time, and thus rainwater collection scores high on the lifetime criterion. The gutters and the roof will have to be kept clean all year long, which is why it scores below average on the maintenance criterion.

Circularity
The application of circularity as a resource can take place under the deck of Irmão, so it scores high on aesthetics because it is not visible to visitors. In addition, the reuse of water will be positive for the environment because useable water that has been taken from nature is recycled, so it also scores high on environmental impact. In terms of potential, circularity scores neutral, because you are dependent on another source supplying the water in the first place. If the water to be reused is sufficiently clean, then circularity can be achieved by means of a storage tank, a pump and the pipes. It is estimated that this will cost around €1.500.(see Appendix B) In terms of maintenance, circularity scores high, as the equipment used requires little maintenance.

Desalinating seawater
Desalination of seawater offers great potential as a source, since Irmão is located by the sea and has abundant salt water available. However, the installation of a desalination plant is very expensive at an estimated cost of over €20.000, requires a lot of maintenance and, compared to the other solutions, is difficult to implement due to its complexity and size. (see Appendix B) The installed equipment is all made to last, but complex, that is why desalinating seawater has an average life time score. In addition, it requires a lot of energy to desalinate water, emitting up to 10 times more CO_2 for one cubic metre of water. And brine containing toxic substances, such as copper and chlorine, remains, posing a risk to marine ecosystems if discharged back into the sea. (IPS, 2019)

Borehole
Since the borehole is already used as a source, it scores very highly on the criteria of ease of implementation. After all, the necessary equipment is already present and connected. It also scores high on aesthetics, as all the equipment is located below deck and thus out of sight of visitors. To be able to use the water from the borehole in the kitchen as well, a Reverse Osmosis (RO) filter will have to be installed, the estimated cost of which is €3.000. (see Appendix B) The installed equipment is all made to last, but complex, that is why the borehole has an average life time score. The borehole scores well in terms of potential, the borehole has proven to be a reliable source in recent years, so based on past experience, the borehole has high potential as a source. To get an even better picture of the borehole as a reliable source, it is recommended to do further research on the borehole to see exactly how big it is and how well it fills up. The investigation of the borehole is a project in itself and therefore falls outside the scope of this study.

As shown in Table 7.1 the borehole scores the highest in the analysis. The borehole scored the highest because, when used correctly, it can provide the restaurant with water in a sustainable and inexpensive way. In addition, the equipment needed is already present and installed. It can be noted that circularity also scores high, which is why the use of circularity will be included in the concepts for the final design as well.

7.2. Water demand reduction

There are various solutions to reduce water consumption. First of all the installation of alternative, more efficient, devices will be discussed. This concerns the complete replacement of existing devices, for example a tap or toilet. Then, , the added value of installing water-saving equipment will be presented. These are additions to the current devices that can reduce the consumption of current devices, while keeping the current user installed.

7.2.1. water efficient devices

As mentioned earlier, besides the type of source from which the water is extracted, reducing the amount of water extracted can also help in reducing Irmão's footprint concerning water. The MCA presented in table 7.2 compares the different water consumers that are present in Irmão. This is done for a standard set of criteria and according to the method described in section Chapter 2. Besides the 7 standard criteria, the analysis will also be conducted with one topic specific criteria, the total water reduction. The total water reduction indicates how much water the use of a more efficient user saves in the end.

Table 7.2: Multi-criteria analysis water devices.

General criteria	**Weight**	Taps	Shower	Toilets	Hoses
Cost	5	3	3	1	5
Ease of implementation	4	3	4	3	4
Maintenance	3	3	3	2	4
Environmental impact	5	3	3	5	3
Esthetics	4	4	5	4	2
Lifetime	2	3	3	4	3
Topic specific criteria					
Total water reduction	5	5	3	5	3
Weighted total		**98**	**96**	**90**	**92**

Taps
Since about 40% of Irmão's water consumption goes to its taps, replacing the current taps with more water-efficient ones could save a lot of water. It is estimated that replacing the taps could result in a flow reduction of 50%, as the current taps have a flow of 7 or more L/min compared more efficient taps with 3 L/min. With an estimated cost of €200 per tap (see Appendix B), implementing more efficient taps scores neutral in terms of cost compared to the other solutions. Furthermore, the implementation of more efficient taps scores neutral in terms of ease or implementation, as a regular plumber can install them. In terms of aesthetics, the taps score high, as for the estimated cost per tap there are many different types of taps to choose from, including types that look the same as current taps.

Shower
By replacing the current shower head with a water-saving shower head, it is estimated that the water flow can be reduced by 50%. As the current one uses 13.4 L/min versus 6-8 litres for water-saving head. Furthermore, replacing the shower head is relatively easy and not very expensive. Replacing the shower head is estimated to cost around €100 to €150 (see Appendix B).

Toilets
Annually, toilets account for 35% of the water used, so replacing them can contribute a lot to reducing water consumption. The disadvantage is that replacing the toilets is relatively expensive and that toilets require more maintenance than the other possible solutions. Replacing one of the current toilets with a more efficient one is estimated to cost between €1.500 and €3.500, depending on the type of replacement chosen.(see Appendix B) Water efficient toilets use 1-2 Liter per flush, leading to an estimated reduction of about 30% to 60% as the current toilets use 5.7 L/flush.

Hoses
The hoses are not a major consumer of water at Irmão. This is because they are used less than the toilets, for example, although they do use a lot of water per minute compared to the other devices. This can be solved by simply installing a different nozzle on the hose, which is why hoses score very well in terms of cost and ease of implementation. For example a water broom, a water broom can save up to 60% if it replaces a high-pressure cleaner that uses 30L/min, since current hoses use just under 15L/min it is estimated that a water broom can save up to 30%. However, installing such a nozzle does make the hose less aesthetically pleasing. The cost of a nozzle is estimated between €25 and €75.(see Appendix B) Overall replacing the hoses score high, this is due to fact that is is very easy and cheap to implement a different nozzle on the hose, so you gain result for very little effort.

In Table 7.2 it can be seen that all devices score 90 or higher in the multi-criteria analysis and thus show potential as possible solutions. Therefore, in all categories of devices, alternative solutions will be included in the concepts for the final design.

7.2.2. Additional saving equipment

Other techniques for reducing water demand include the use of water-saving devices. Water saving devices refer to devices that can limit the flow of a device. Examples that will be considered are: aerators and flow regulators. A study by the Department of Architecture and Civil Engineering at the University of Bath has shown that, on average, a percentage reduction in flow rate leads to a reduction in water consumption of 46% of the decrease in flow rate, i.e. if the flow rate of a tap is reduced by 50%, the water consumption decreases on average by 46% multiplied by 50% is 23% (Pombo et al., 2018). However minimal flow rates are required for the tap to be operational, for example flow rates less than 5 l/min is not recommended for kitchen taps while taps in the bathroom can be as low as 1 l/min when fitted optimally (AECB, 2019).

Aerators

Aerators are devices that can be easily implemented into the current taps and can decrease the discharge of a tap by mixing the water with air. Research has showed that water consumption can be reduced up to an amount of 40% largely at a cost of only a couple euros per aerator (da SilvaLuiz Gustavo Costa Ferreira NunesAnna Elis Paz SoaresSimone Rosa da Silva, 2017). Currently, all taps in the kitchen are supplied with such aerators, the taps in the bathrooms are not. The cost of an aerator is around €10. (see Appendix B)

Flow regulators

Flow regulators consist of a colour coded body and a dynamic o-ring. The o-ring responds to pressure changes and changes shape to adjust the amount of water flowing through the flexible gap. These regulators can be installed in taps, shower heads and other devices. The flow rate is pre-determined and is independent of the pipe pressure. A combination of flow regulator and aerator is also possible and can straighten the flow if necessary, a flow regulator costs between €5 and €10 (WRAS, 2021). (see Appendix B)

As the analysis in chapter 6 pointed out that there are large differences between the flow rates of different devices and that there are some devices with a relatively high flow rate, it is concluded that both water saving equipment have great potential. In addition, the solutions are easy to implement and relatively cheap, which makes it interesting to apply.

7.3. Drainage system

There are several ways to address the current problem, which is that the waste water storage tank is too small for the amount of wastewater being discharged. As a result, as described in Section 6, it often has to be emptied twice a day by a farmer. This causes CO_2 emissions from the tractor and costs Irmão €8.000,-. In short, it is important to find an alternative or to improve the system.

The two main solutions are either to increase the storage for waste water or to reduce the amount of water to be discharged. This way, the tank does not have to be emptied twice a day to ensure that it does not overflow. It is very important that this does not happen, because otherwise the water from the waste water storage tank ends up in the dunes, which is strictly prohibited and bad for the environment. Increasing the storage can be done by installing a second waste water storage tank, a tank that simply stores the black water until it is collected. As for reducing the amount of run-off water, as mentioned earlier, there is much to be gained in terms of devices. Especially the toilets in this case, a toilet that uses no water at all will be examined for the purpose of this study. Consideration will also be given to the installation of a composting tank, which is a tank in which the waste water from the toilets is processed through fermentation. This creates fertiliser and the waste water is processed directly, which means it does not have to be done by a third party. The compost tank will be used in combination with a toilet that uses little or no water. Apart from the toilets, the taps in Irmão also have a large contribution to the amount of waste being drained. Therefore, the solutions given in Section 7.2 can reduce the amount of run-off water as well.

The possible options are compared by means of a multi-criteria analysis, based on the 7 predefined general criteria. In addition, the topic specif criterion 'Total waste water reduction' is considered. As the

Table 7.3: Multi-criteria analysis Drainage system.

General criteria	Amount	Septic tank	Compost tank	Compost toilet	Biogas plant
Cost	5	3	1	3	1
Ease of implementation	4	3	2	4	1
Maintenance	3	4	3	2	3
Environmental impact	5	3	5	5	5
Esthetics	3	5	4	2	5
Lifetime	3	4	4	3	5
Topic specific criteria					
Total waste water reduction	5	1	5	5	5
Weighted total		**86**	**96**	**102**	**98**

amount of waste water produced by a solution is important for both its sustainability and the drainage system.

Installation of an extra waste water storage tank
With the installation of an additional waste water storage tank, the amount of waste water to be disposed of remains the same, hence it scores low on the topic specific criterion of waste water reduction. It does make the disposal system a bit more sustainable in terms of emission of CO_2, because the farmer that empties the tank has to drive less often and therefore emits less CO_2. With about €2000 to €2500 in total cost of implementation, a waste water storage tank scores neutral in terms of cost. (see Appendix B) However, the waste water storage tank is out of sight for the visitors and regular toilets can be used, which leads to a high score in terms of aesthetics.

Compost tank
The installation of a composting tank is relatively expensive, as it should be used with a toilet that uses little or no water, such as the vacuum toilet. Apart from the cost of the tanks itself, which is €6.000 to €9.000 for three tanks, vacuum toilets have to be installed as well to implement the system properly. (see Appendix B) Central composting tanks are good for the environment because the excrement is turned into compost without the use of chemicals. This eliminates the need to transport waste water, as well as the need to purify the waste water, a process that involves the use of chemicals and consumes power.

Compost toilet
The composting toilet collects urine and faeces separately and does not use water. The urine can be used for watering plants. The excrement is collected in a bag per toilet and converted to fertiliser in a separate tank, hence the high environmental score. The disadvantage is that someone has to empty the toilets every day, hence the low score on maintenance. Such a composting toilet costs about 700 euros. (see Appendix B)

Biogas plant
Implementing a biogas plant can have a very positive impact on the environment and the reduction of waste. The black water coming from the toilets is converted into organic fertilizer through natural fermentation, which can be used to feed plants. In addition, biogas is generated, which is a clean renewable energy source and can be used, for example, for cooking. Furthermore, wastewater no longer needs to be transported or treated, a process that uses chemicals and consumes energy. More information can be found in Section 10.1 It should be noted, however, that a biogas plant is very expensive, with a price tag of approximately €15.000 euros. (see Appendix B)

The multi criteria analysis in Table 7.3 shows that the compost tank, compost toilet and vacuum toilet all score relatively high compared to the additional waste water storage tank. Therefore, the use of a composting tank, the composting toilet and the vacuum toilet will all be included in the possible concepts.

7.4. Concepts

In this section, different concepts will be brought together based on the solutions that have potential. Because in the previous sections different solutions per topic proved to be promising, this section will also look at which solutions can be used in combination. These concepts will then be estimated in terms of total implementation costs, contribution to sustainability and ease of implementation. In order to compare the concepts properly, the contribution to sustainability and the costs of implementation will be assessed and ranked against each other. Note that the annual water reduction of the taps is estimated using aerators and the annual water reduction of the shower is estimated using a push button

7.4.1. Concept 1

The first concept involves replacing current water devices with more efficient water devices and installing water-saving equipment. Furthermore, vacuum toilets will be installed to save water. These toilets are each equipped with its own pump to pump the water away and can be connected to the existing drainage network. This means that the infrastructure of the current water supply network does not need to be changed, making the concept easy to implement and the costs low compared to other concepts. Table 7.4 shows the implemented solutions including their prices and a schematic representation of the water network of this concept is shown in figure 7.1. As mentioned before, this network is identical to the current network.

Table 7.4: Solutions water system concept 1.

Solution	**Amount**	**Estimated price**	**Estimated total cost**	**Estimated annual water reduction [m^3]**
Sensored toilet taps	5	€200	€1.000	40
Water efficient shower head	1	€100 - €150	€100	35
Push button in the shower	1	€50	€50	-
Waterbroom on the hose	1	€25 - €100	€25 - €100	31
Aerators on the toilet taps	5	€10	€50	-
Flow regulators on the kitchen taps	5	€5 - €10	€25 - €50	172
Vacuum toilet	5	€1.500	€7.500	230 - 460
		Total	**€8.750 - €8.900**	**508 - 738 m^3**

The calculation of the estimated annual water consumption is presented in appendix B and is based on the estimates made before.

Easy of implementation: 4/5

The aerators, flow regulators and water broom can be installed by Irmão itself. The installation of the vacuum toilets and waterless urinals will have to be done by a specialised 3rd party. The taps and push buttons can be installed by a regular plumber. Compared to the other concepts, this leads to a overall ease of implementation of concept 1 above average.

Sustainability: 1/5

In terms of sustainability, concept 1 scores the lowest compared to the other concepts. Although Irmão's footprint in terms of water consumption has been significantly reduced, a significant amount of waste water is still produced. This waste water is not treated locally either, but by a third party and, as before, has to be collected by a farmer from the region.

Total cost estimation: €10.500

All solutions together have an estimated purchase cost of €8.750 to €8.900. Add to this an estimated installation cost of around €2000 and the total cost estimate for concept 1 of is approximately €10.500.

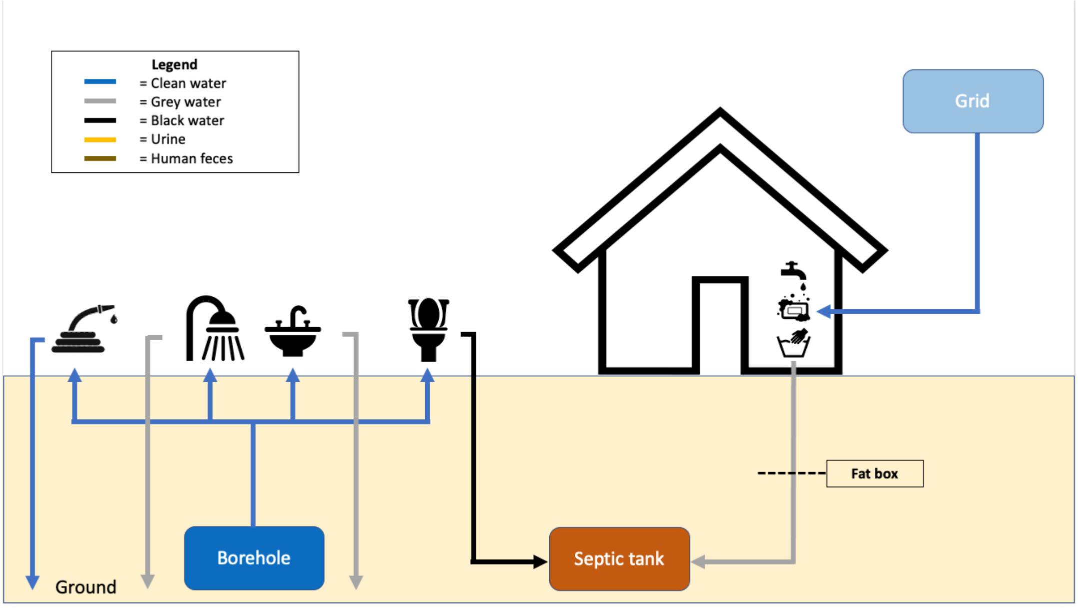

Figure 7.1: Water network Concept 1

7.4.2. Concept 2

Concept two is largely similar to concept one. However, in concept two a compost toilet is used. This toilet immediately separates the urine from the feces, after which the urine is transported to the waste water storage tank. No water is used for the discharge, so not only water is saved, but also the waste water storage tank does not fill up as quickly. The faeces is collected in a bag in the toilet itself. When the bag is full, it is manually removed by the staff and deposited in a compost tank. Here, the feces will then compost, after which it can be used as fertiliser. Table 7.5 shows the implemented solutions including their prices and a schematic representation of the water network of this concept is shown in figure 7.2.

Table 7.5: Solutions water system concept 2.

Solution	Amount	Estimated price	Estimated total cost	Estimated annual water reduction [m^3]
Sensored toilet taps	5	€200	€1.000	40
Water efficient shower head	1	€100 - €150	€100	35
Push button in the shower	1	€50	€50	-
Waterbroom on the hose	1	€25 - €100	€25 - €100	31
Aerators on the toilet taps	5	€10	€50	-
Flow regualtors on the kitchen taps	5	€5 - €10	€25 - €50	172
Compost toilet	5	€3.000	€15.000	768
		Total	**€16.250 - 16.400**	**1046 m^3**

The calculation of the estimated annual water consumption is presented in appendix B and is based on the estimates made before.

Easy of implementation: 5/5
The aerators, flow regulators and water broom can be installed by Irmão itself. The installation of all other proposed solutions can be done by an ordinary plumber. Since the composting toilets do not need to be connected to pipes, they are very easy to implement. This ultimately leads to a high overall ease of implementation of concept 2.

Sustainability: 3/5
In terms of sustainability, concept 2 scores average compared to the other concepts. Irmão's footprint

in terms of water consumption will be reduced considerably. Furthermore, composting the human waste residues will not only contribute to reducing the amount of waste/waste water Irmão produces. In addition, this waste will be converted into fertiliser that can be used as nutrition for plants.

Total cost estimation: €17.000
All solutions together have an estimated purchase cost of €16.250 - €16.400. Add to this an estimated installation cost of around €600 and the total cost estimate for concept 1 of is approximately €17.000.

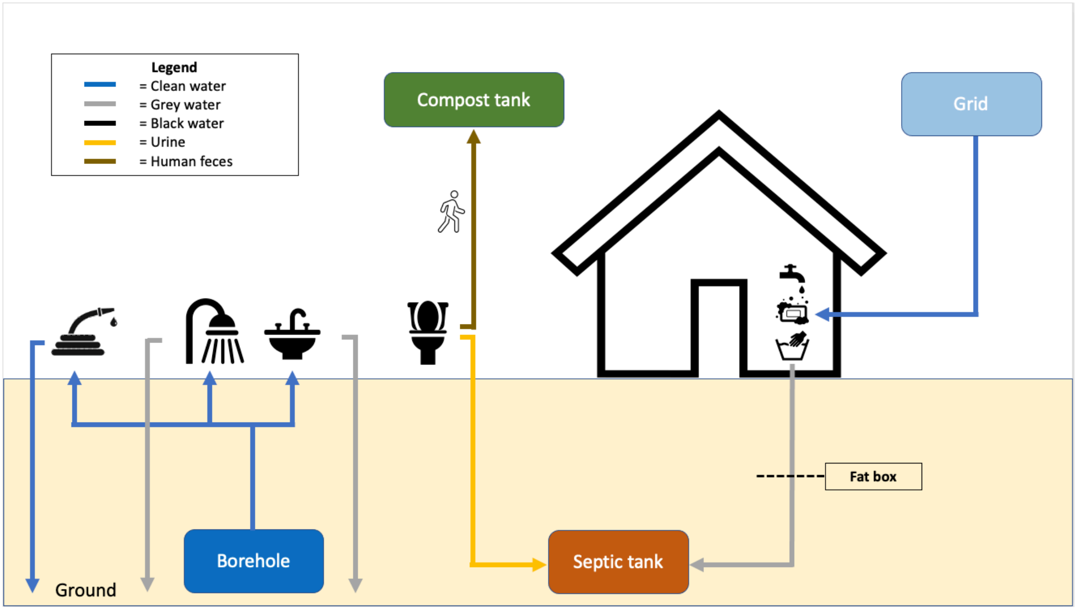

Figure 7.2: Water network Concept 2

7.4.3. Concept 3

In concept three, circularity is applied. The water from the shower and toilet taps is collected in a basin and reused for the hoses and for flushing the toilets. Since the amount water form the shower and toilets taps alone is not enough to supply all the hoses and toilets, the toilets will still be flushed with water from the borehole when necessary. Three water less urinals will also be installed, next to the current toilets, so that men can urinate without using water. In addition, the current water devices will again be replaced by more efficient water devices and water-saving equipment will be used. Table 7.6 shows the implemented solutions including their prices and a schematic representation of the water network of this concept is shown in figure 7.3.

Table 7.6: Solutions water system concept 3.

Solution	Amount	Estimated price	Estimated total cost	Estimated annual water reduction [m^3]
Sensored toilet taps	5	€200	€1.000	40
Water efficient shower head	1	€100 - €150	€100	35
Push button in the shower	1	€50	€50	-
Waterbroom on the hose	1	€25 - €100	€25 - €100	31
Aerators on the toilet taps	5	€10	€50	-
Flow regualtors on the kitchen taps	5	€5 - €10	€25 - €50	172
Waterless urinals	3	€500	€1.500	77
Reuse of shower and toilet water	1	€1.500	€1.500	121 - 242
		Total	**€4.250 - 4.400**	**467 - 597 m^3**

The calculation of the estimated annual water consumption is presented in appendix B and is based on the estimates made before..

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In order to be able to reuse the water from the shower and toilet taps, a storage tank with a pump will have to be installed to collect the water and pump it to the hoses and toilets. It is estimated that buying and installing this will cost a total of approximately €1500.

Easy of implementation: 4/5 The aerators, flow regulators and water broom can be installed by Irmão itself. The waterless urinals will have to be installed by a specialist and the installation of all other proposed solutions can be done by an ordinary plumber. Implementing this concept is relatively easy, but more difficult than concept 2, hence it scores 4/5 on ease of implementation.

Sustainability: 2/5
In terms of sustainability, concept 3 scores just below average compared to the other concepts. As Irmão's footprint in terms of water consumption will be reduced considerably. But concept 3 does not convert waste into a valuable resource like concept 2 converts human waste into fertiliser.

Total cost estimation: €5.500
All solutions together have an estimated purchase cost of €4.250 - €4.400. Add to this an estimated installation cost of around €1.000 and the total cost estimate for concept 3 of is approximately €5.500.

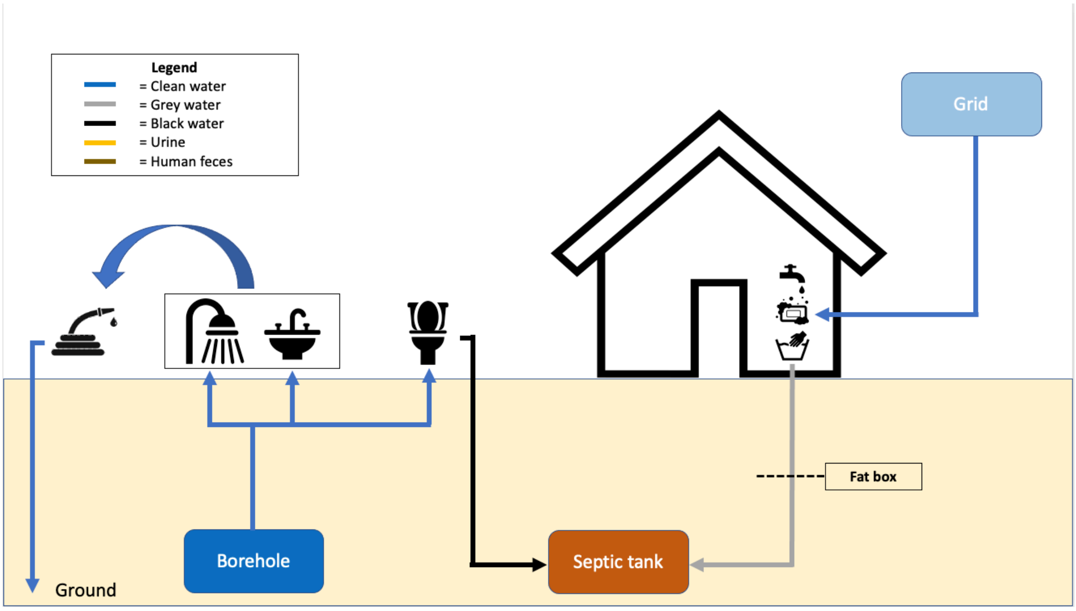

Figure 7.3: Water network Concept 3

7.4.4. Concept 4

The fourth concept again makes use of circularity. The water from the shower and toilet taps, plus the water from the dishwasher, is reused for the hoses and to flush the toilets. The current toilets will be replaced by vacuum toilets and waterless urinals will be installed. This ensures that there is enough water to run both the hoses and toilets on used water. Furthermore, water-saving equipment will again be implemented and the current water devices will be replaced by water-saving devices. Table 7.7 shows the implemented solutions including their prices and a schematic representation of the water network of this concept is shown in figure 7.4.

Table 7.7: Solutions water system concept 4.

Solution	Amount	Estimated price	Estimated total cost	Estimated annual water reduction [m^3]
Sensored toilet taps	5	€200	€1.000	40
Water efficient shower head	1	€100 - €150	€100	35
Push button in the shower	1	€50	€50	-
Waterbroom on the hose	1	€25 - €100	€25 - €100	31
Aerators on the toilet taps	5	€10	€50	-
Flow regulators on the kitchen taps	5	€5 - €10	€25 - €50	172
Vacuum toilets	5	€1.500	€7.500	230 - 460
Waterless urinals	3	€500	€1.500	77
Reuse of shower and toilet water	1	€1.500	€1.500	121 - 242
		Total	**€11.750 - 11.900**	**697 - 1057 m^3**

The calculation of the estimated annual water consumption is presented in appendix B and is based on the estimates made before.

Easy of implementation: 3/5
The aerators, flow regulators and water broom can be installed by Irmão itself. The waterless urinals and vacuum toilets will have to be installed by a specialist and the installation of all other proposed solutions can be done by an ordinary plumber. Implementing this concept is more difficult than concept 3, hence it scores 3/5 on ease of implementation.

Sustainability: 3/5
In terms of sustainability, concept 4 scores higher than concept 3, since more water saving solutions are implemented. Ensuring that the concept saves more water than concept 3 and thus contributes more to sustainability.

Total cost estimation: €13.500
All solutions together have an estimated purchase cost of €11.750 - €11.900. Add to this an estimated installation cost of around €2.000 and the total cost estimate for concept 3 of is approximately €13.500.

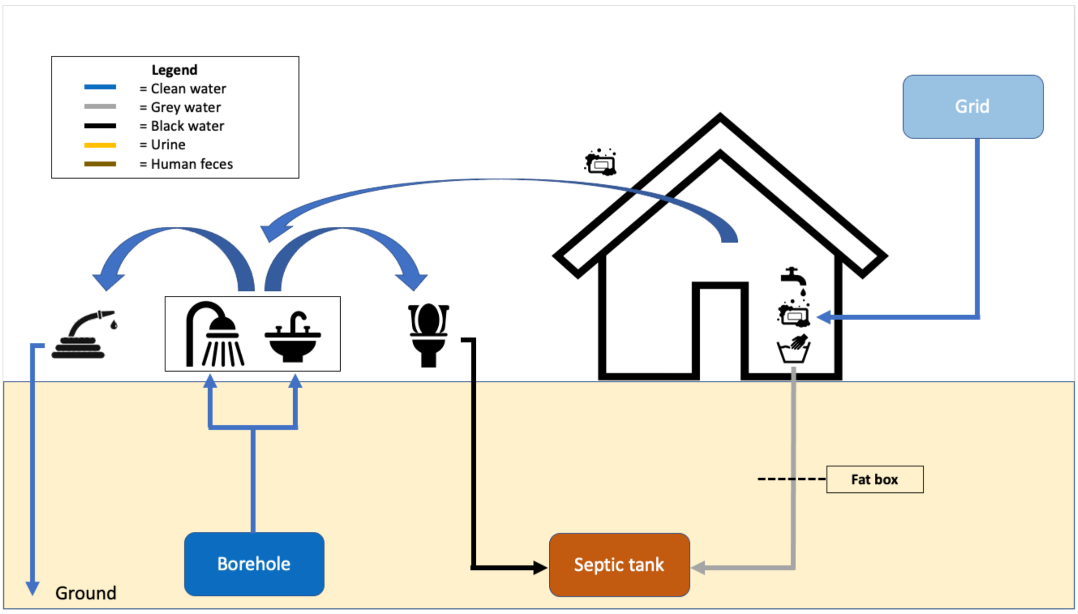

Figure 7.4: Water network Concept 4

7.4.5. Concept 5

In the fifth concept, a compost tank is implemented as well as circularity. The water from the shower and taps is reused for the hose and toilets. The current toilets are replaced by vacuum toilets and water less urinals are installed. The water less urinals are connected to the waste water storage tank and the vacuum toilets to a central composting tank. In this compost tank the black water will be converted into fertiliser. Furthermore, water-saving equipment will again be implemented and the current water devices will be replaced by water-saving devices. Table 7.8 shows the implemented solutions including their prices and a schematic representation of the water network of this concept is shown in figure 7.5.

Table 7.8: Solutions water system concept 5.

Solution	Amount	Estimated price	Estimated total cost	Estimated annual water reduction [m^3]
Sensored toilet taps	5	€200	€1.000	40
Water efficient shower head	1	€100 - €150	€100	35
Push button in the shower	1	€50	€50	-
Waterbroom on the hose	1	€25 - €100	€25 - €100	31
Aerators on the toilet taps	5	€10	€50	-
Flow regualtors on the kitchen taps	5	€5 - €10	€25 - €50	172
Vacuum toilets	5	€1.500	€7.500	230 - 460
Waterless urinals	3	€500	€1.500	77
Reuse of shower and toilet water	1	€1.500	€1.500	121 - 242
Central composting tanks	3	€2.200	€6.600	0
		Total	**€18.350 - 18.500**	**697 - 1057 m^3**

The calculation of the estimated annual water consumption is presented in appendix B and is based on the estimates made before.

Easy of implementation: 2/5
The aerators, flow regulators and water broom can be installed by Irmão itself. The waterless urinals and vacuum toilets will have to be installed by a specialist, as well as the compost tank and the installation of all other proposed solutions can be done by an ordinary plumber. Implementing this concept is quite difficult, bus easier than concept 6, thus scoring 2/5 on easy of implementation.

Sustainability: 4/5
In terms of sustainability, concept 5 scores higher than concept 4. The amount of water saved is about the same, but concept 5 processes toilet wastewater via a compost tank. This means that waste water is processed directly and converted into a valuable resource, namely fertiliser. Concept 6 goes a step further by also producing biogas and therefore scores higher in terms of sustainability.

Total cost estimation: €21.500
All solutions together have an estimated purchase cost of €18.350 - €18.500. Add to this an estimated installation cost of around €3.000 and the total cost estimate for concept 5 of is approximately €21.500.

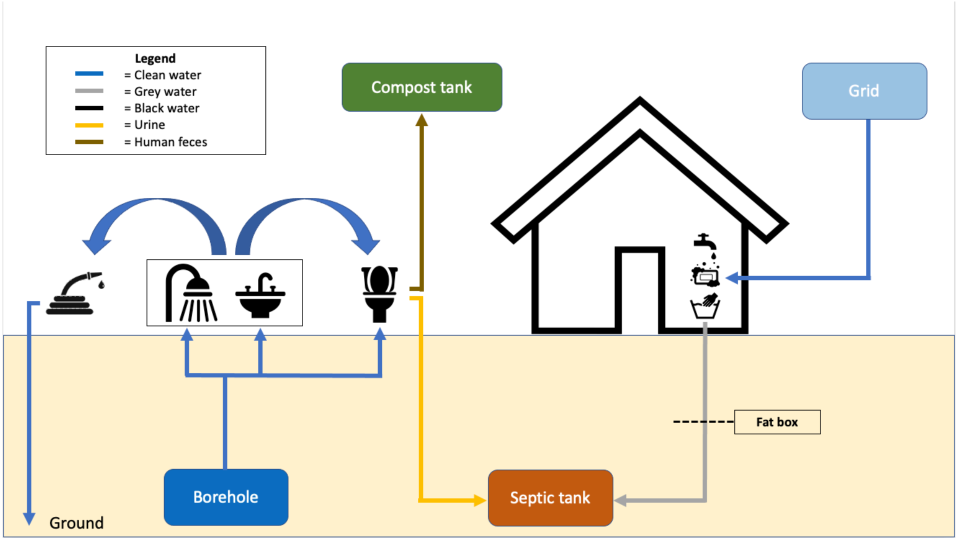

Figure 7.5: Water network Concept 5

7.4.6. Concept 6

The sixth concept is completely independent off the grid. The water for the shower, toilet taps, dishwasher and kitchen taps is obtained from the borehole. The borehole water is filtered through a reverse osmosis filter in order to guarantee the required water quality. The water from the shower, toilet taps and dishwasher is used for the hoses and for flushing the toilets. And the black water that comes from the toilets is discharged into a biogas plant. Where the feces is converted into fertilizer and biogas (for more information and benifits of the biogas plant see Section 10.1). Table 7.9 shows the implemented solutions including their prices and a schematic representation of the water network of this concept is shown in figure 7.6.

Table 7.9: Solutions water system concept 6.

Solution	**Amount**	**Estimated price**	**Estimated total cost**	**Estimated annual water reduction [m^3]**
Sensored toilet taps	5	€200	€1.000	40
Water efficient shower head	1	€100 - €150	€100	35
Push button in the shower	1	€50	€50	-
Waterbroom on the hose	1	€25 - €100	€25 - €100	31
Aerators on the toilet taps	5	€10	€50	-
Flow regualtors on the kitchen taps	5	€5 - €10	€25 - €50	172
Vacuum toilets	5	€1.500	€7.500	230 - 460
Waterless urinals	3	€500	€1.500	77
Reuse of shower and toilet water	1	€1.500	€1.500	121 - 242
RO filter	1	€3.000	€3.000	0
Biogas plant	1	€15.000	€15.000	0
		Total	**€29.750 - 29.900**	**697 - 1057 m^3**

The calculation of the estimated annual water consumption is presented in appendix B and is based on the estimates made before.

Easy of implementation: 1/5

The aerators, flow regulators and water broom can be installed by Irmão itself. The waterless urinals and vacuum toilets will have to be installed by a specialist, as well as the biogass plant and the installation of all other proposed solutions can be done by an ordinary plumber. The implementation of this concept is the most difficult of all concepts, hence it scores 1/5 in terms of easy of implementation.

Sustainability: 5/5

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Concept 6 has the highest score in terms of sustainability. Water is saved both by circularity and by the implementation of water-saving means. Irmão is fully self-sufficient by pumping water from the borehole and filtering it. Furthermore, the waste water from the toilets is processed by means of a biogas plant and converted into fertiliser and biogas.

Total cost estimation: €32.500
All solutions together have an estimated purchase cost of €29.750 - €29.900. Add to this an estimated installation cost of around €2.500 and the total cost estimate for concept 3 of is approximately €32.500.

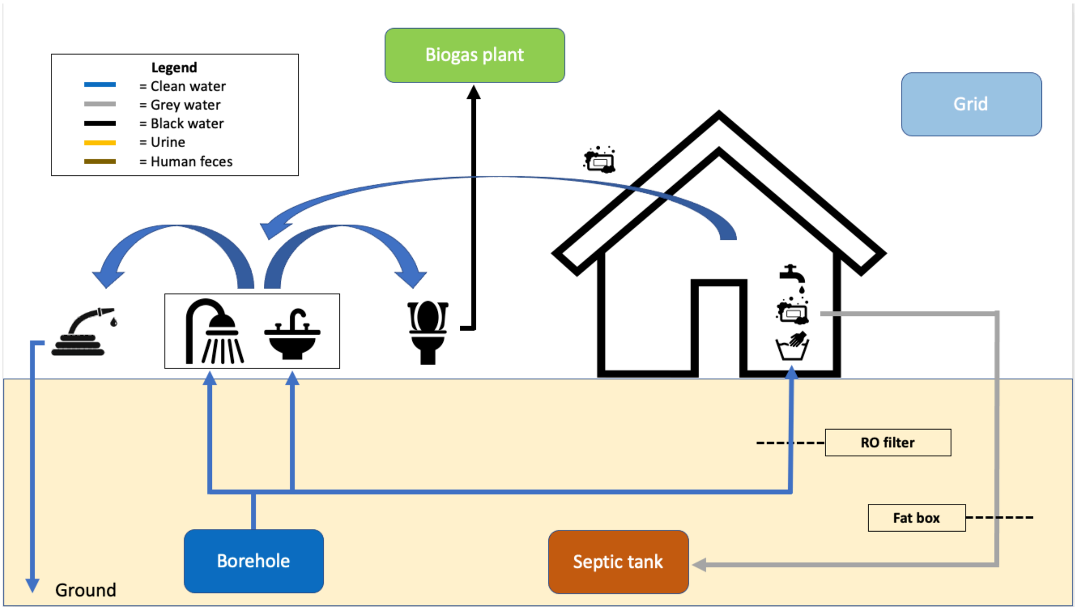

Figure 7.6: Water network Concept 6

7.5. Summary water system design concepts

The analysis of the possible solutions shows that Irmão could best use the borehole as an alternative water source or apply circularity. As these methods can provide the restaurant with water in a sustainable and cheap way. Furthermore, the use of more efficient water devices for taps, showers, toilets and hoses proved to have potential. The same applies to the use of water-saving devices such as aerators and flow regulators, as these can save up to 23% of the water used. And they are easy to implement and relatively cheap, costing no more than €10 each. In terms of solutions to the drainage problem, a biogas plant has been shown to contribute the most in terms of sustainability. Since the black water coming out of the toilets can be converted into fertiliser and biogas. Thus producing clean renewable energy and eliminating the need to transport or treat wastewater, a process that uses chemicals and consumes energy. Based on these findings, in Section 7.4 various potential concepts have been compiled.

From the concepts elaborated in Section 7.4, in consultation with the client, a concept was chosen that best met the client's wishes to improve present Irmão in terms of sustainability. Concept 4 was chosen because the client wants to be as sustainable as possible without having to make drastic changes to the existing drainage network as these are under the deck of Irmão. Concepts 5 and 6 were therefore discarded, as these will result in drastic changes to the existing drainage network. Furthermore, the client is also afraid of unpleasant odours in the case of the compost toilet, as a result of which concept 2 was rejected. Concepts 1 and 3 fall short of concept 4 in terms of annual estimated water savings with 508-738 m^3 and 467-597 m^3 respectively, compared to 697-1057 m^3.

In addition, there is a concept that stands out from the other concepts in terms of sustainability, namely concept 6. However, this concept is the most expensive and the most difficult to implement. It is therefore advised to apply this concept if Irmão has to be relocated and therefore completely rebuilt. In that way, the correct pipes can be laid immediately during reconstruction. Because this concept contributes most to the sustainability of Irmão in terms of water, it will also be further elaborated in Chapter 8. It is estimated that 697-1057 m^3 of water will be saved annually, this makes concept 6, together with concepts 4 and 5, one of the most estimated water-saving concepts. Only concept 2 has a higher estimated water saving of 1046 m^3 per year, but the client does not like the use of compost toilets due to the chance of unpleasant odors, as mentioned earlier. In addition with concept 6, all waste water will be treated locally using the biogas plant, while providing biogas and fertiliser. Hence, concept 6 will contribute most to Irmão's sustainability.

8

Water system designs worked out

In this chapter, the two designs that appeared to be the most promising in chapter 7.4, namely design concept 4 and design concept 6, are discussed in more detail. As discussed in chapter 7.4, the design of concept 4 will be an adaptation of the current system of Irmão, the design will therefore be named *improved water system Irmão* from now on. Because design concept 6 is difficult to implement in the current situation, but offers a lot of perspective, this concept will be used for the design of a beach restaurant in the future. This design, in which the restaurant can be built from scratch, will be called *future water system Irmão* in the course of the report. Each design contains a number of items that has been worked out in separate subsections. In addition, an overview of the expected results and a financial overview of the designs is provided. In order to be able to compare the water systems of the two designs with the current water system, the figure presenting the current system can be found in is shown again in figure 6.2.

8.1. Design 1: improved water system Irmão

The first concept that will be worked out in more detail, is a system combining water saving equipment, circularity, vacuum toilets and waterless urinals. An schematic overview of the design is presented in figure 8.1. The three component of the design will be further elaborated, as well as the expected results of the design and the financial overview.

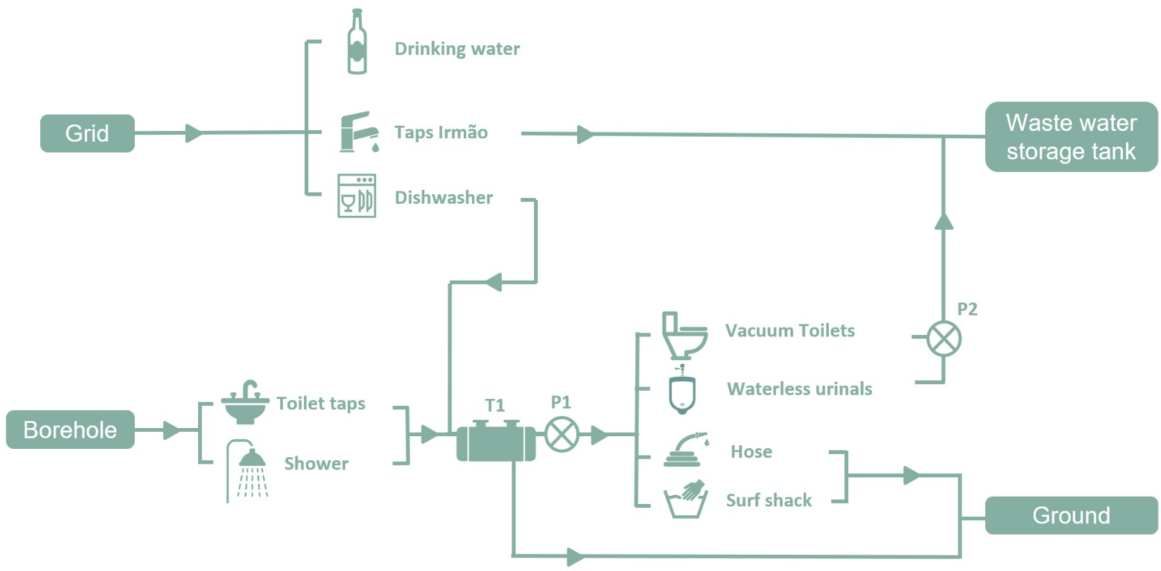

Figure 8.1: Systematic display of the design in which the framework of the current restaurant is maintained.

8.1.1. Water saving equipment

The four types of water saving equipment that are used during the calculations in this study are provided and explained below:

Figure 8.2: Examined watersaving equipment used for the designs. In the design, flowregulators (a) that guarantee a constant, predefined flow rate can be implemented in the taps inside the restaurant. Furthermore, the design contains sensor taps (b) in the toilet, an efficient shower head (c) and an efficient water broom (d) that can be used for cleaning activities.

Waterflow regulators

As described in chapter 7.2.2 flow regulators maintain a predefined flow rate that is independent from the prevailing line pressure. In this concept flow regulators providing a constant flow of 6 l/m must be implemented in every tap inside Irmão and the tap in the Gypsy wagon. The tap in the dishes area, in the pizza area and the tap in the kitchen are estimated to be the largest consumers. Therefore the average flow reduction of these taps are used to estimate the reduction of water consumption due to the flow regulators. This leads to an average reduction in flowrate of 40.8%. Following the method described in chapter 7.2.2 a reduction in water usage of 20.4% is expected to be achieved (WRAS, 2021). The costs per flow regulator is €6,00 leading to a total cost of €36,00 (Appendix B.5).

Aerated sensor toilet taps

The taps in the toilet currently do not contain any water saving equipment and have a relatively high flow rate of 6,9 l/m. A type of tap as shown in figure 8.2(b). has a flow rate of 3l/min (Appendix B.5). This leads to a water consumption reduction of 28%. The sensor ensures that the tap is turned off during hand washing and that the tap cannot be left on by accident. This leads to an estimated reduction of 20%. It is expected that after implementing this tap there will be a reduction in water use of the toilet taps of 42%. The cost per toilet tap €70, this results in a total cost of €350 (Appendix B.5)

Efficient shower head combined with a push button

This efficient shower head maintains a powerful jet while using only 6 l/m (Appendix B.5). This leads to a 28% reduction. In addition, the push button leads to an estimated 20% reduction. This results in a total reduction of 42% in the water used for showering. The costs of the push button and shower head are €45 and €120 euros respectively. Resulting in a total cost of €165.

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Waterbroom
The water hose shown in figure 8.2(d) can be used for cleaning the terrace and the wind screens. According to expectations, this will reduce the water consumption of the hose by 30%. The cost of such a waterbroom is €50 (Appendix B.5).

An overview of the expected results of the water saving equipment in provided in table 8.1

Table 8.1: Overview expected results and cost of implementing watersaving equipment in the system.

	Action	Expected water consumption before implementation (m^3/yr)	Expected water consumption after implementation (m^3/yr)	Costs (€)
Taps Irmão	Implementation of flowregulators	859	682	36
Toilet tap	Replace by sensor toilet taps	158	91	350
Shower	Replace efficient showerhead	116	67	165
hose	Usage of water broom	104	73	50

8.1.2. Vacuüm toilets and waterless urinals

In this design, the five toilets have been replaced by vacuum toilets with a consumption of 1 litre per flush, as shown in the figure 8.3(a) . The vacuum toilets studied can be sold and supplied by a highly regarded Dutch company called BioCompact. The 50 mm pipes of the five vacuum toilets must be connected to a 1.5 kW pump (P1), which ensures a vacuum in the pipes. When the toilet is flushed, the human waste is pumped with one litre of water to a small storage tank. From this tank, wastewater can be pumped to the waste water storage tank. Since the vacuum toilets use only 1 litre per flush instead of 5.6 litres per flush like today's toilets, it is expected that 82% less water will be used for the toilets. The cost of vacuum toilets and the accompanying equipment is €15.025.

In addition, this design includes three waterless urinals for men. As the name suggests, no water is used while flushing the toilet. It is recommended to divide the toilets into men's and women's toilets so that three urinals can be purchased instead of five. The urine is collected and immediately sealed by a membrane called MB Active Trap. This membrane ensures that there is no unpleasant odour in the toilets. The MB Active Trap must be replaced every month, which leads to a fixed cost of €300 per year. In addition, this solution is also attractive from a hygienic point of view, since no aerosols are formed during the flushing process as no water is used. Aerosols can contain viruses and bacteria. The cost of adding 3 waterless to the design are €1.155.

(a)

(b)

Figure 8.3: Image of the vacuum toilet (a) and the waterless urinal (b) both implemented in design 1. The items can be purchased and transported by a company called BioCompact.

In this concept, the vacuum toilets are combined with the waterless urinals. The water use in the toilets is expected to be reduced by 89%. The additional 7% compared to only the vacuum toilets is due to the addition of waterless urinals. It is estimated that on average a man uses the urinal four out of five times, leading to a further 40% reduction in water usage compared to vacuum toilets alone. In total, this results in 89% less water estimated to be used in the toilets. The costs include the five vacuum toilets, three waterless urinals, two tanks, vacuum pump, spare vacuum pump and shipping costs: €16.200. An overview is given in table 8.2. The system described and the corresponding costs were determined in consultation with the owner of the company BioCompact. For further specifications of vacuum toilets and waterless urinals, the toilets and costs, one can contact BioCompact.

Table 8.2: Overview of the expected results of using vacuum toilets in combination with waterless urinals.

	Action	Expected water consumption before implementation (m^3/yr)	Expected water consumption after implementation (m^3/yr)	Costs (€)
Toilet	Placement of 5 vacuum toilets & 3 waterless urinals	768	82	16,200

8.1.3. Circularity

This design also incorporates circularity. We have chosen to re-use the water from the dishwasher, toilet taps and shower to rinse the vacuum toilets, for the garden hose and for cleaning the wetsuits in the surf house. After showering, washing hands and washing the dishes the water will contain some pollution. However, the quality of this water is sufficient for the use of the garden hose, toilet and surf shack (Royal Horticultural Society, n.d.). It must be noted that ecological soap must be used for the shower, toilet taps and dishwasher so that no chemicals end up in the environment. As presented in figure 8.1, the water from the dishwasher, toilet taps and shower flows into a 2000 litre tank (T1) after which it can be pumped to the devices by a centrifugal pump (P1) with a capacity of 30 l/m.

When the vacuum toilets, waterless urinals and water saving equipment are also installed, it is estimated that approximately 322 m^3 of water will enter the tank annually. This volume is more than enough to supply the surf shack, garden hose and toilets, which will use an estimated 215 m^3 annually. The excess water can be drained to the ground.

The cost where the storage tank, pump and extra pipeline are included, is €1.300. After the use of water saving equipment, vacuum toilets and waterless urinals, this circularity is estimated to reduce the amount of water that must be withdrawn from the borehole by 215 m^3. The costs and specifications of the circularity are given in Appendix B.5.

8.1.4. Overview results design 1: improved water system Irmão

The combination of using water-saving equipment, vacuum toilets, waterless urinals and circularity results in an estimated 16% reduction in water obtained from the public grid. In addition, a reduction of 87% of water extracted from the borehole is predicted. It is also expected that 59% less volume will be discharged into waste water storage tank. As described in chapter 6.2.3, the waste water storage tank is emptied at the end of the day when there is a reasonable amount of volume in the tank. In the new situation, it is expected that the tank will be emptied at relatively less volume. In this design it is assumed that the waste water storage tank is emptied on average when 3 m^3 is present. This means that the tank will need to be emptied approximately 270 times a year, which is a reduction of 53%. This reduction does not only saves on costs, but also reduces emissions because the amount of visits of the farmer, that comes by tractor, is reduced. An overview of the expected results of concept 5 are provided in table 8.3, the result are compared to the estimated values in the current situation.

8.1.5. Financial overview design 1: improved water system Irmão

The investment cost of this concept consists of the cost of the water-saving equipment, vacuum toilets and waterless urinals. Together this gives an amount of €18.100, a margin of 10% for unforeseen costs

Table 8.3: Result overview design 1: improved water system Irmão.

Result overview 'Improved water system Irmão'	**Current system (m^3/yr)**	**Yearly costs current situation (€)**	**Design 1: 'Improved water system Irmão' (m^3/yr)**	**Yearly costs design 1 (€)**	**Yearly savings (€)**
Water from grid	1108	€ -4.831	933	€ -4.067	€ 764
Water from borehole	1205	€ -	159	€ -	€ -
Volume to waste water storage tank	2010	€ -8.000	827	€ -3.760	€ 4.240
Total	-	€ -12.831	-	€ -7.827	€ 5.004

gives €19.900. The fixed annual cost for replacing the membranes in the waterless urinals is €300. This design requires relatively little maintenance but to cover unforeseen repairs the maintenance cost is estimated at €200 per year. The annual net savings is given by the yearly saving (€5.000) minus the yearly costs (€500), resulting in a annual net saving of €4.500. With a discount rate of r = 4%, a payback of 5 year is calculated. An overview is provided in table 8.4

Table 8.4: Financial overview of design 1: 'Improved Irmão water system'.

Financial overview 'Improved Irmão'	**Year 0**	**Year 1-25**
Investment	€ 19.900	€ -
Fixed costs	€ -	€ 300
Maintenance costs	€ -	€ 200
Savings	€ -	€ 5.000
Cash flow	€ -19.900	€ 4.500
Discounted payback time (r=4%)	5 year	

8.2. Design 2: future water system Irmão.

The second concept includes, as in the previous concept, water-saving equipment, circularity, vacuum toilets and waterless urinals. In addition, the toilets in this design are connected to a biogas plant, furthermore, the restaurant is no longer connected to the public grid. This is possible due to a reverse osmosis filtration of the borehole water. The design is schematically presented in figure 8.4, and will be further explained in this subsection. Since water saving equipment, circularity, vacuum toilets and waterless urinals is similar to the improved Irmão concept it is not further elaborated in this subsection.

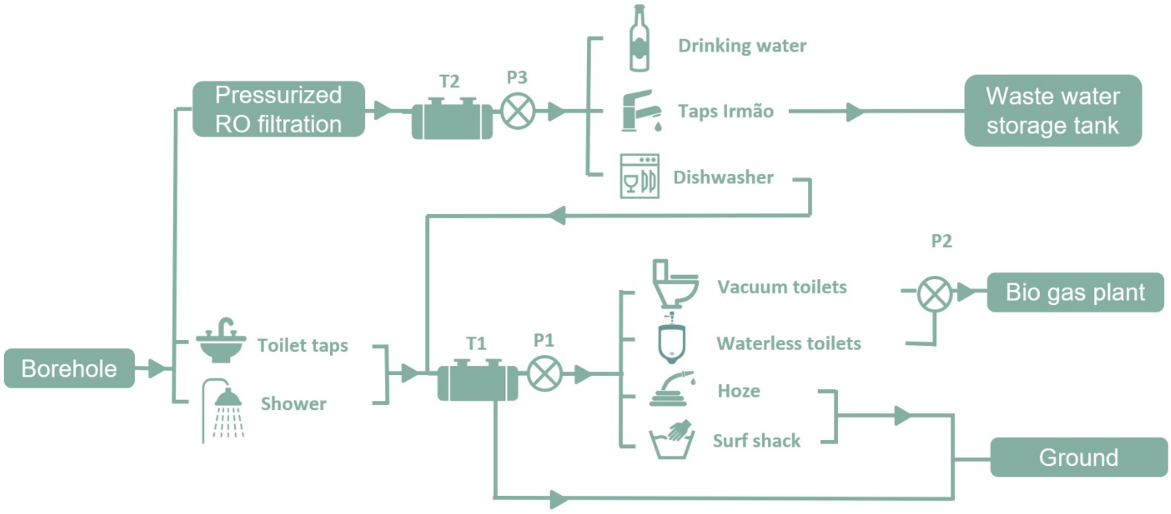

Figure 8.4: Systematic display of infrastructure proposal in which the system can be build form scratch, i.e. the future beach pavilion.

8.2.1. Pressurized RO filtration

In this design, the connection to the public network is cut. To achieve this, all the water used must be withdrawn from the borehole. To ensure that the water is potable, it is filtered through a pressurised RO filtration. In this way, sufficient quality is guaranteed. However, it is strongly recommended that a groundwater sample is examined in order to determine the correct type of filtration. Depending on the contamination of the groundwater, other and most of the time cheaper filtration systems such as ultra filtration could also be possible. Such a sample can be send to a company called Lenntech, which is specialised in water treatment and has the expertise to offer a system that best suits Irmão's situation. Depending on the outcome of the examination of the quality of the groundwater, and in consultation with the municipality, it may be decided to use water directly from the ground for the washing machine or possibly even for the taps in Irmão.

According to an employee of Lenntech, the cost of such a RO filtration system with a filter capacity of 1000 l/hr, will be around €3.000. As this is an imprecise estimate, a conservative cost of €6.000 is chosen in this study. A 3000 litre tank (T2) is needed to store the filtered water before it can be pumped to the taps, to the dishwasher and to the drinking water machine where minerals have to be added. Pumping to these devices can be done by a centrifugal pump (P3) with a capacity of 150 l/min. The costs for the tank and pump are around €1.500 and €200, respectively. This results in an investment cost of €7.700. Because the filter must be replaced every 7 months and the cost of a filter is approximately €200, the fixed costs of having this system are €340 per year. To cover unforeseen maintenance costs, €60 is budgeted annually.

To supply the dishwasher, taps in Irmão and the drinking water machine with enough water, 933 m^3 must be filtered from the borehole annually. However, by adding this filter to the system, 933 m^3 less will be received from the grid, thus avoiding emissions, since the water supply company uses fossil energy, among other things. The energy used in this design comes entirely from solar panels. The generation of energy is further explained in chapter 13.

Since the lifetime of such a filtration system is approximately 20 years, the annual cost of filtering 993 m^3 litres per year can be calculated. The depreciation of the filter system is €7.700/20yr = €385/yr. To this should be added the annual costs and the repair costs of €400 in total. This results in an annual cost of €785 to filter a quantity of 993 m^3 per year. This converts to €0,80 per m^3. Compared to the cost of 1 m^3 obtained from the public grid, namely €4,36 per m^3, it is clear that this solution is cost effective.

8.2.2. Biogas plant

In addition to filtration, this design includes a biogas plant in which human waste and other types of waste are converted into a mixture of methane and CO_2. Chapter 11.2 explains the biogas plant in more detail and presents the results.

In this design, the waste containing water, faeces and urine is pumped to the biogas plant by means of the vacuum pump (P2). Annually, a volume of 62 m^3 is pumped to the biogas plant. The cost of such a bio gas plant is €15.000 including construction. Because this plant has to be painted annually with black paint, the fixed costs are €120 per year. The costs of the bio gas plant are based on a study performed on a biogas plant with similar dimensions and a similar design (Castro-GonzÃ et al., 2015).

8.2.3. Overview results design 2: future water system Irmão

The combination of the use of water-saving devices, vacuum toilets, waterless urinals, circularity, RO filtration and a biogas plant results in a 100% reduction in water taken from the public grid. In addition, a 9.4% reduction in water taken from the borehole is predicted. Because the toilets drain into the biogas plant, the volume that flows into the waste water storage tank will be even lower compared to design 1. In this design, it is expected that 66% less volume will be discharged into the waste water storage tank. As with design 1, it is assumed that the tank is emptied when an average of 3 m^3 is present. This means that the tank will need to be emptied approximately 227 times per year, a 60% reduction. An overview of the expected results of design 2 can be found in table 8.5, the results are compared to the estimated values in the current situation.

Table 8.5: Overview of the expected results of design 2: Future water system Irmão

Result overview 'Future water system Irmão'	**Current system (m^3/yr)**	**Yearly costs current situation (€)**	**Design 2: 'Future water system Irmão' (m^3/yr)**	**Costs (€)**	**Yearly savings (€)**
Water from grid	1108	€ -4.831	0	€ -	€ 4.831
Water from borehole	1205	€ -	1092	€ -	€ -
Volume to waste water storage tank	2010	€ -8.000	683	€ -3.200	€ 4.800
Total	-	€ -12.831	-	€ -3.200	€ 9.631

8.2.4. financial overview design 2

The investment costs of this concept consist of the costs of the water-saving equipment, the vacuum toilets, the waterless urinals, circularity, RO filtration and the biogas plant. Together this gives an amount of €40.800, a 10% margin for unforeseen costs gives €44.880. The fixed annual costs for painting the biogas plant and replacing the membranes in the waterless toilets and the filter together amount to €700. In addition to the annual €60 for RO filtration, an additional €400 is calculated as unforeseen repair costs. This amounts to a total annual repair cost of €460. In net terms, this gives an annual saving of €8.471. Using a discount rate of r = 4%, a payback period of 7 years is calculated. This means that after 7 years this design is profitable. An overview is given in table 8.6.

Table 8.6: Financial overview of design 2: 'Future Irmão water system'

Financial overview 'Future Irmão'	**Year 0**	**Year 1-25**
Investment	€ 44.880	€ -
Fixed costs	€ -	€ 700
Maintenance costs	€ -	€ 460
Savings	€ -	€ 9.631
Cash flow	€ -44.880	€ 8.471
Discounted payback time (r=4%)	7 year	

8.3. Summary of the worked out water system designs

This chapter serves to summarise chapter 9 in which two designs are fully elaborated. The first design is an addition to the current water system of Irmão, therefore it is called *improved water system Irmão*. The second design was designed without limitations of the current system, i.e. starting from scratch. It is therefore a design for a future situation, which is why it is called *future water system Irmão*.

Design 1: Improved water system Irmão
Design 1 in which the system of the current restaurant is modified includes the following items:

- Installation of water-saving equipment
- Installation of vacuum toilets
- Installation of waterless urinals
- Implementation of circularity

After installing these items, it is expected that 175 m^3 less water must be obtained from the public grid, annually, a decline of 16%. This saves some CO_2 emissions, namely 19.25 kg per year. In addition, the combination of the above items reduces the amount of water that needs to be pumped from the borehole by 1046 m^3 annually, a 59% reduction. Furthermore, it has been calculated that this design results in a reduction in the number of times the waste water storage tank has to be emptied. Namely a reduction of 305 times a year, a decrease of 53%. Because the farmer has to empty the waste water storage tank less often, some emissions will be saved every year. Since the materials that is used in this design will likely cause more emissions due to construction and shipping than is saved due to the design, this design will not be more sustainable than the current situation in terms of emissions. However, it can be said that because 1221 m^3 of water is saved annually, this design is more sustainable than the current system in terms of using exhaustible resources. An overview of these results is presented in table 8.3.

From a financial point of view, it appears that this design becomes profitable after 5 years if a discount rate of 4%, which is a common value, is used. The investment cost is €19.900 and the annual cost of the design is €500. The result of the design is a saving of €5.000 per year, which comes down to a net saving of €4.500 per year. If the present restaurant remains in use for more than five years after the adaptation of design 1, it becomes profitable. In case the restaurant has to move within these 5 years, the equipment such as vacuum toilets, waterless toilets, tanks and pumps can be used in the future restaurant. Because this also costs money and probably not all equipment can be used, the payback period will be longer than five years in the case that the restaurant has to move within 5 years.

Design 2: Future water system Irmão
Design 2 in which a system is proposed for a future restaurant that can be build from scratch, contains the following items:

- Installation of water-saving equipment
- Installation of vacuum toilets
- Installation of waterless urinals
- Implementation of circularity
- Disconnection from the grid by filtering water from the borehole
- Installation of biogas plant

From the calculations it is expected that by installing these items, 1108 m^3 per year less can be obtained from the public grid, this is a reduction of 100% and equals a saving of 122 kg CO_2 per year. In addition, it is expected that 113 m^3 less water will need to be pumped from the borehole each year, a reduction of 9%. In total, Irmão uses 53% less water in this design. It has also been found that this design reduces the number of times the waste water storage tank has to be emptied. Namely a reduction of 348 times per year, which equals 60%. An overview of these results is shown in table 8.2.4. Again, in terms of emissions, this design will not be more sustainable, at least initially, but due to the large annual reduction in water use, this design is still considered more sustainable.

In terms of finances, it appears that this design will be profitable after 7 years if a discount rate of 4% is used. The investment costs are higher than in the other design, namely €44.880. The annual costs are €1.160 and the savings are €9.631 per year. This amounts to a net saving of €8.471 per year. The financial overview can be found in table 8.6.

III
Waste management

9
Waste management analysis

In order to keep the beach and the protected dune environment clean, it is important that the waste disposal system is properly regulated. In addition, reducing the amount of waste also contributes to achieving a more sustainable operation. Therefore, in this chapter, the current waste management of Irmão is analysed. In section 9.1, the production of waste and type of produced waste is presented. Hereafter, the way Irmão processes its waste is analysed in section 9.2.

9.1. Waste production

In order to get a good understanding of how much waste Irmão actually produces, a measurement is done according to the methodology in Chapter 2. Four categories were examined, namely plastic, paper, glass and rest waste. The rest waste is the remaining waste produced in the kitchen, pizzeria, dishwashing area and bar. The tables with the results of these measurements per category can be found in the appendix table D.1. These results were then converted into graphs using MATLAB. These graphs are presented in figures 9.1(a), 9.1(b), 9.1(c) and 9.1(d), being plastic, paper, glass and rest waste respectively.

In addition to the total number of bags per day, the average bags per day is also shown by the red line. The figures show that almost no waste is produced on Mondays, only a small amount of rest waste. This is because Irmão is closed on Mondays, the rest waste that is produced is generated during cleaning. Also, more waste is usually generated during the weekends, because there are more customers and therefore more staff, who all produce more waste. As indicated in the appendix table D.1, these averages are 3.07 (plastic), 4.57 (paper), 2.86 (glass) and 20.07 (rest). According to multiple measurements conducted, the average weight of a waste bag is 5.94 kg. This results in 18.2 kg, 27.1 kg, 17.0 kg and 119.2 kg per day respectively.

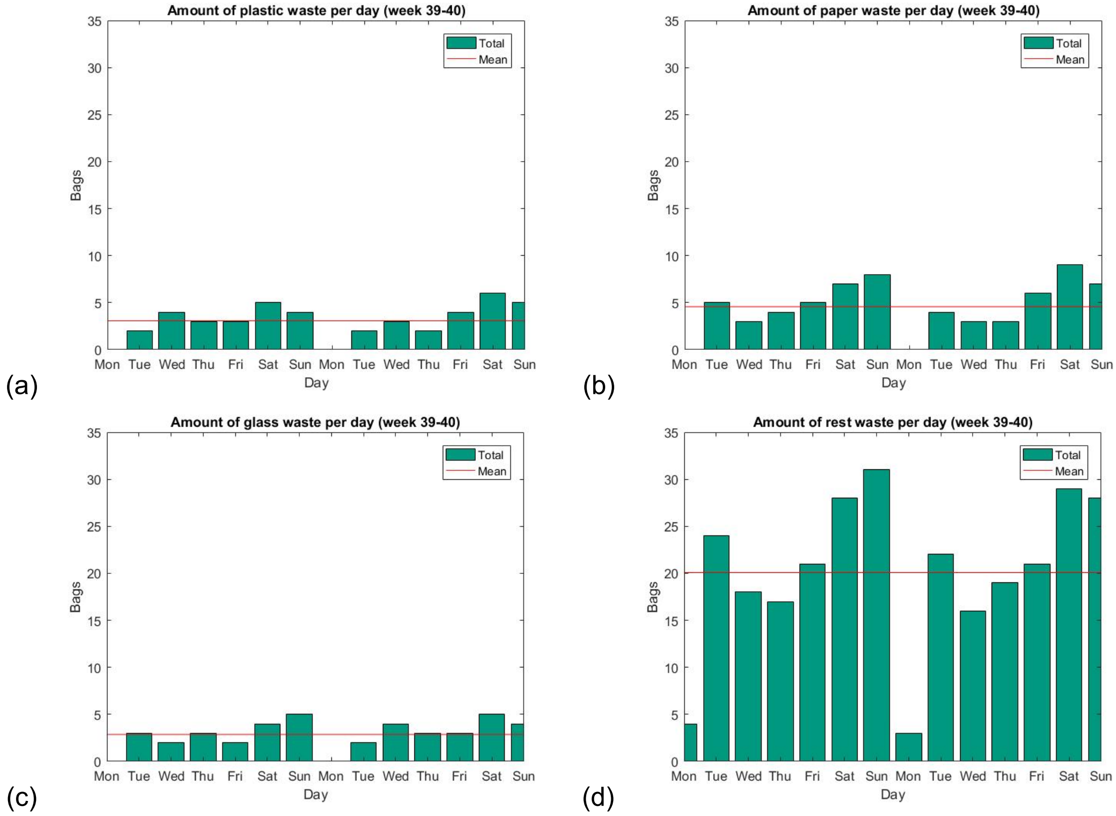

Figure 9.1: Production of waste at Irmão week 39-40 (a) Plastic waste (b) Paper waste production (c) Glass waste (d) Rest waste

In order to determine how Irmão's waste management can become more sustainable, it is determined for each category of waste whether there is room for improvement within the scope of this study. The first category, plastic waste, like the other categories paper and glass, is collected separately and then recycled by the municipal waste collection service. According to (T. Degermann, personal communication, September 10, 2021), almost all of this plastic comes from packaging of products and deliveries. This is something the owners of Irmão do not want to change due to hygienic considerations. Therefore, reducing the amount of plastic used during operations of the restaurant is left out of the scope. However, it is recommended not to buy plastic products if possible, since the emissions are 2.9 kg CO_2 per kg plastic production and 0.5 kg CO_2 per kg plastic recycling (Mortensen et al., 2021). However, the use of cardboard products is recommended, as the footprint of 0.94 kg CO_2 per kg cardboard and therefor has less negative impact on the environment (ecology, n.d.).

Paper is the second category of waste that is produced at Irmão. Again, the production of paper waste is due to the packaging of the suppliers of the products. Therefore, the sustainability of paper waste production is also out of scope for this study.

The production of glass waste is the third category. Most of the glass waste originates from glasses that break due to clumsiness of the operators and glass from soft drink bottles that are collected per crate when the bottles are empty, according to (T. Degermann, personal communication, September 10, 2021). The owner has indicated that he does not want to use other packaging for the soft drinks, as this has a better appearance compared to cans, for example. Thus, human error and the owner's wishes mean that the production of glass waste can also be left out of the scope.

The only category that then remains is residual waste. This consists mainly of non-recyclable products, errors in separation from other categories and organic waste, i.e. green and food waste (detailed in section 11.1). As it was difficult to find out the exact distribution, the share of organic waste was slightly less than half, according to the owner (T. Degermann, personal communication, September, 2021). As a result, the daily amount of organic waste was assumed to be 50 kg.

When this 50 kg on an average day in week 39-40 is compared with the cover model using a linear relationship, figure 9.2 is obtained. Deriving the weekly organic waste volume from this figure leads to an annual organic waste production of 12.5 tonnes. This organic waste will otherwise end up on landfills for further processing. According to (Lee et al., 2018), this would result in emissions of 2.8 tonnes of CO_2 and 190 kg of CH_4. It should be noted that methane has 35 times more impact on the environment than CO_2.

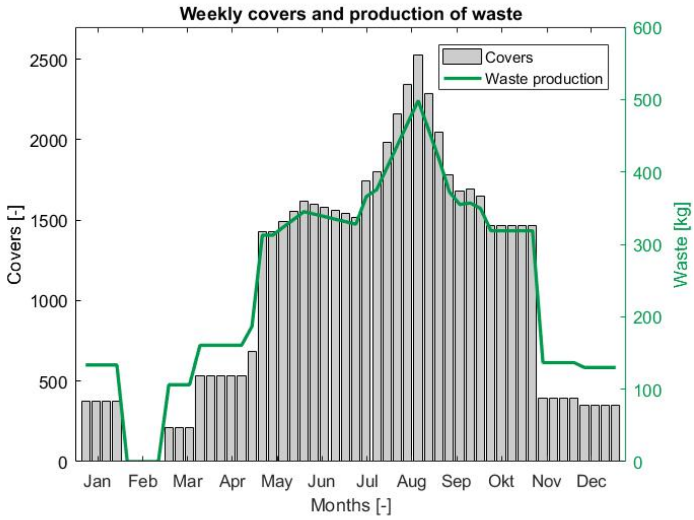

Figure 9.2: Yearly production of organic wast

9.2. Waste Processing

As indicated in the previous paragraph, Irmão is already separating its waste into four categories at this moment. The waste is separated at the restaurant and put into different bags, which are then put in separated containers at Irmão. If these small containers at Irmão are full of waste, the bags are thrown away by category into large bins at the parking area, see figure 9.3. These waste bins are for all the restaurants on Praia Do Castello.

Figure 9.3: Waste bins parking area

The problem of the current situations is that the bins at the parking area are not big enough to store all the waste from all the restaurants until it is collected. As it is, restaurants, including Irmão, are often forced to place the waste bags next to the bins. These loose bags create an unpleasant smell in the car park and therefore cause a nuisance to all beach visitors. In addition, stray dogs get the chance to tear open the bags when looking for food, if the bags are placed next to the waste bins. The result is that the waste, which has been separated with great difficulty by the restaurants, is thrown together again and spread across the parking area. In this way, the waste ends up directly in nature, instead of being collected for recycling.

The large containers in the car park are emptied by external parties. These parties recycle the categories glass, plastic and paper. The rest waste, which accounts for the largest proportion of the waste produced, ends up on a landfill. Here, the waste is processed, and the energy generated is to be used again. The costs of disposing the waste from the containers is a municipal service. This costs nothing but is included in the taxes of the restaurant. (T. Degermann, personal communication, September 10, 2021)

9.3. Summary waste system analysis Irmão

The analysis of the current waste management of irmão consists of two parts; waste generation and waste treatment. During the analysis of the waste production it was found that the waste is already separated into four categories. These categories and the average amount produced are as follows:

- 18.2 kg plastic/day
- 27.1 kg paper/day
- 17.0 kg glass/day
- 119.2 kg rest/day

The categories plastic paper and glass are beyond the scope of this study, due to responsibility of delivery companies, owners wishes and human erros. Within the rest waste category, the focus is on making the organic waste that is currently produced more sustainable. This is about 50 kg per day and results in approximately 12.5 tonnes per year. This results in emissions of 2.8 tonnes of CO_2 and 190 kg CH_4 if it ends up in a landfill.

In terms of waste treatment, a problem has arisen in the car park of Irmão, which it shares with two other beach restaurants. Because there is not enough capacity in the current waste containers, waste bags are placed next to the containers. This results in inconvenience in the form of smells and sight. It also attracts wild dogs, which spread the waste all over the parking area.

10
Waste management solutions

To tackle the waste problem of Irmão, as indicated in section 9.2, and in order to make the waste management more sustainable, solutions are presented in this chapter. As indicated in section 9.2, only the rest waste is considered in making waste management more sustainable. This chapter is divided into three sections. First, the solutions that reduce the total rest waste are given in section 10.1. Then, in section 10.2, the solutions for the treatment of rest waste are given, currently the biggest problem at Irmão as indicated in 9.2. Last, in section 10.3, a comparison between different solutions is made with one MCA for waste reduction and one MCA for waste treatment.

10.1. Solutions for reducing waste

In order to have a more sustainable waste management, one has to look at the options that reduce the amount of waste that is now being produced. In this section, these options, or solutions, will be discussed.

Winnow / Leanpath

The first solution for reducing the food waste is to integrate a software program, called Winnow (Winnow solutions ltd, 2021) or Leanpath (Leanpath, Inc, 2021). These programs focus on getting to know how much food waste is produced on a daily basis. This is measured by an integrated system which looks at the type and the weight of the wast being thrown away. The type of waste is identified by a camera looking into the food waste bin. At the same time, the weight of the waste is determined by a scale. This way Irmão gets a better insight in their food waste and could eventually optimize the purchasing of the food and the served portions. Leading to a reduction in the amount of food wasted and, at the same time, to a financial benefit.

Too good to go

Another option is to look at a solution for distributing the food that is produced already, before it becomes waste. This can be achieved by using ”Too good to go” (Too Good To Go International, 2021). This is an anti-food waste app designed for both the supplier and the consumer of food. The goal of the app is to give joining companies the opportunity to get acquainted with new customers and become more sustainable at the same time. The operating principle is based on the fact that partners, in this case Irmão, sell the food that was going to be thrown away for a lower price at the end of the day. This way the customers get a meal with discount and Irmão makes additional profit and gets in to contact with potential new customers.

Blast chiller

The third solution for reducing waste is based on the principle of cooling the food at a higher rate. This can be done by installing a blast chiller in stead of a refrigerator. A blast chiller blows cool air onto the food inside the chiller. This operating principle ensures that the food is chilled from 70°C to 3°C within 90 minutes, almost three times faster than a refrigerator according to Zhang and Sun (Zhang and Sun, 2006. Therefore, the time the food is in the danger zone, being 6°C to 70°C, in which bacteria grow rapidly and spoil the food, is reduced. This allows for the food to be maintained at a high quality for a longer period of time as well as a reduction of the amount of wasted food.

Composting machine
A different solution is the implementation of a composting machine at Irmão. A large part of the rest waste produced at Irmão is food waste. According to a study conducted by BSR (for Social Responsibility, 2014), 84% of food waste ends up in the trash. Instead of throwing away a lot of unused food, composting is a good option in trying to reduce the food waste. With composting, organic waste is mixed with plenty of water, air and soil containing microorganisms, eventually turning the waste into compost. This organic waste can include anything from newspapers, napkins, leaves, grass, woody material and food waste (especially fruit and vegetables). Besides the environmental benefits in reducing the amount of solid waste, the compost can be used as fertilizer for growing vegetables and fruits at Irmão. The financial benefit of having to pay less for retrieving waste by a removal company, also comes with this process.

Biogas plant
The last solution for waste reduction is to build a biogas plant. This plant works on the principle of anaerobic digestion by methanogen bacteria of both organic waste and human manure. In this process, biogas, which can be collected for personal use at Irmão, and a slurry, very similar to compost, are produced. This biogas consists for the large part of methane and carbondioxide, with a low amount of hydrogen, nitrogen and hydrogensulfide (Radtke, 2016). By implementing such a biogas plant, Irmão can generate energy from waste treatment. Because this is the case, biogas can be called a renewable fuel and is therefore an ideal solution for waste management in order to become more sustainable.

10.2. Solutions for treatment of waste

As indicated in section 9.2, Irmão is now struggling with the problem of too much waste being produced by the two beach restaurants adjacent to the car park. This results in an accumulation of waste around the container intended for this purpose. In this section, two solutions to this problem are proposed.

Underground waste containers
The first solution given to the accumulation of waste is to have a underground waste containers. This allows for the waste that is produced by the beach restaurants to be stored underground instead of above ground. In this way, it can be ensured that the waste will not produce any nuisance to visitors. VConsyst (VConsyst B.V., 2021) underground waste containers are recommended for this purpose. This company offers user-friendly and multifaceted underground waste containers for separated waste collection. This means that there is a compact container above ground for each type of waste into which the waste can be deposited. The storage container underground can be up to 7 m^3. Since this is a solution that helps all three beach restaurants of praia do Castello, the investment can be shared equally.

Sealed waste area
Another option, which is also a cheaper one, is to move the current rubbish containers to a more remote part of the car park and then seal it off with fences. This would ensure that stray dogs can no longer reach the loose waste. Which will reduce the amount of waste scattered throughout the car park. An additional advantage of a more secluded location is that beach visitors will be less bothered by the stench of the waste. The installation of fencing around the waste containers can be undertaken by an arbitrary fencing company. The cost of the construction can again be divided between the three beach restaurants of Praia do Castello.

More waste containers
The last and actually easiest solution is to place more waste containers. This would allow the waste that does not fit in the current containers to be deposited there. This will at least prevent waste bags from being placed next to the containers. The positive consequence is that there are then no more waste bags that are dragged across the entire parking area by wild dogs, causing a nuisance for visitors.

10.3. Alternative comparison

In order to make a good choice between the different solutions, a multi-criteria analysis is used in this section. The solutions with the highest score will then be included in the integrated design of chapter 16.

Waste reduction
First, the solutions for waste reduction from section 10.1 will be discussed. The different solutions, respectively winnow/leanpath, too good to go, blast chiller, composting machine and biogas plant, are indicated as columns in table 10.1. The criteria for comparing the different solutions are shown as rows. Again, a distinction is made between the general criteria and the topic-specific criteria. The general criteria are the same as in the previous chapters, being cost, ease of implementation, maintenance, environmental impact, aesthetics and lifetime. The subject-specific criteria for the waste reduction are in this case user-friendliness and the actual waste reduction. User-friendliness is a criteria because people usually find it tedious enough to do the waste, so it helps if it is as easy as possible. Waste reduction is ultimately the goal of the new solution and therefore also an important criterion.

Table 10.1: MCA waste reduction.

General criteria	**Weight**	**Win./Lean.**	**TGTG**	**Blast chiller**	**Composting**	**Biogas**
Cost	5	2	5	3	3	3
Ease of implementation	3	4	3	2	4	4
Maintenance	2	4	5	2	3	3
Environmental impact	5	3	2	1	4	5
Esthetics	4	4	3	3	3	2
Lifetime	2	4	5	2	3	5
Topic specific criteria						
User friendly	3	3	2	5	3	4
Reduction of waste	5	1	1	2	5	5
Weighted total		83	87	71	105	113

As can be seen, the different criteria have been classified according to importance with a weighting factor. The most important criteria carry the most weight, as they have the greatest influence on the final choice. In this case, this comes down to the following criteria: cost, environmental impact and waste reduction. This is because the owner would prefer an economical solution. In addition, environmental impact is important, as the aim of the project is to find the most sustainable solution possible. For this category, the criteria waste reduction is important, as this is the main reason for the solution.

Winnow / Leanpath
Costing €1.200 per month, the implementation of winnow/leanpath is the most expensive option of all. It will also have a neutral impact on the environment, but significantly less than composting or a biogas plant. The reduction in waste will be small, about 2-8%.

Too good to go
Since Too Good To Go is free to use, it scores highly in terms of costs. Furthermore, the impact on the environment and the reduction of waste will differ little, as almost no fresh food is thrown away. This will make it difficult to implement Too Good To Go at Irmão.

Blast chiller
The investment cost of a blast chiller is €2.500 and therefore scores neutral in this segment. On the other hand, the impact on the environment is bad, since it takes a lot of energy to make the blast chiller work. Furthermore, food could be kept a little longer than at present, but a large reduction in waste cannot be expected.

Composting machine
The investment of a composting machine is €12.500 and therefore scores neutral. Composting reduces the emission of greenhouse gases, so it scores well on environmental impact. Because a large part of the waste is composted, the reduction of waste is also significant.

Biogas plant
Investing in a biogas plant costs €15.000, and therefore also scores neutrally. Furthermore, it has the greatest impact on the environment as it prevents most greenhouse gases. Due to anaerobic digestion, the reduction of waste is also significantly more than the first three options.

Looking at the final scores of the solutions, two solutions score significantly higher, namely 100 or more. Hence, composting and biogas will be included in the final design in the next chapter.

Waste treatment
In addition to the multi-criteria of waste reduction, a MCA is also made for waste treatment. This can be seen in table 10.2. The two tables largely resemble each other, except that the topic specific criteria reduction of waste has been replaced by nuisance of waste. This is an important criteria, because the nuisance that the waste now causes is the motive for coming up with a new solution. Furthermore, the solutions on the horizontal axis have been replaced by the solution belonging to the waste treatment, being a large underground hole or a closed waste area.

Table 10.2: MCA waste treatment.

General criteria	**Weight**	**Underground**	**Sealed**	**More containers**
Cost	5	2	4	5
Ease of implementation	3	2	4	5
Maintenance	2	2	3	3
Environmental impact	5	4	3	2
Esthetics	4	5	2	3
Lifetime	2	5	3	3
Topic specific criteria				
User friendly	3	5	3	4
Nuisance of waste	5	5	3	3
Total		30	25	28
Weighted total		110	91	101

The same distribution of weighting factors is used as in the MCA for waste reduction. This ensures that in this case, the criteria cost, environmental impact and nuisance of wast have the greatest influence on the final choice. Compared to the previous section, reduction of waste has been replaced by nuisance of waste as the new main criterion. This criterion is important because one does not want to cause any inconvenience to either the users or the visitors when handling the waste.

Underground waste containers
The cost of the underground waste containers is €50.000. This is the most expensive option, and therefore scores the lowest. The impact on the environment scores the highest, as the waste is stored underground and sealed. This also means that the waste is no longer a nuisance for visitors.

Sealed waste area
The costs of the enclosed waste area are more bearable, as the fences are the only cost item. The impact on the environment and the nuisance caused by the waste both score neutral as well, since the waste is stored in a closed manner, but it is still a visual nuisance for the visitors.

More waste containers
The option of more waste containers is the cheapest, as only a few extra containers need to be purchased, and therefore scores high in the cost category. However, extra containers have a negative impact on the environment, as they are usually made of plastic, which is very harmful. Nuisance will decrease somewhat, but the stench of the waste bags will remain.

Examining the final score of all three solutions, it becomes clear that the option of the large underground hole is the best and will therefore be further elaborated in the integrated design.

10.4. Summary waste system design concepts

Numerous solutions have been put forward for reducing organic waste production. These solutions are successively Winnow / Leanpath, Too good to go, Blast chiller, composting machine and biogas plant. After carrying out a multi-criteria analysis, it turned out that the composting machine and the biogas plant score the highest and are therefore used in the *Improved Irmão Scenario* and the *Future Irmão Scenario* respectively.

For waste treatment, three different solutions have been proposed, being underground waste containers, enclosed waste area and more waste containers. The multi-criteria analysis showed that the underground waste containers score the highest. This concept will be applied in both the *Improved Irmão Scenario* and the *Future Irmão Scenario*.

11

Waste management solutions worked out

After the current waste management in the areas of waste generation and waste treatment have been discussed in chapter 9 and the solutions for improvement in chapter 10, this chapter elaborates on the best solutions. First the composting machine as a solution in section 11.1, then the biogas plant in section 11.2. Finally, the underground waste containers are explained in section 11.3.

11.1. Improved Irmão waste management

The solution to the concept of the *Improved Irmão Scenario* is the composting machine, see figure 11.1. As briefly indicated in section 10.1, the following things can be composted:

- Fruits and vegetables
- Dairy products
- Grains and bread
- Egg- and seashells
- Meat and fish
- Paper napkins and coffee filters

Other waste such as plastic, metal and glass from packaging, for example, cannot be composted; these are recycled. Therefore, these products must be separated and treated separately in order to prevent them from ending up in landfills like other residual waste.

Figure 11.1: Composting machine (TOGOHB, 2021)

As shown in section 9.1, this would amount to a total of 12.5 tonnes of organic waste. This then results in emissions of 2.8 tonnes of CO_2 and 190 kg of CH_4. During composting, aerobic bacteria convert this organic waste into compost, heat, carbon dioxide and ammonium. The carbon in compost is very stable, which leads to less conversion of carbon into CO_2. Besides, the aerobic bacteria prevent the forming of CH_4. This reduces the CO_2 emissions by 80% and the CH_4 emissions by 79%. This amounts to a saving of 2.26 tonnes of CO_2 and 147 kg of CH_4 per year. On the other hand, the composting machine needs energy to help this process along, totalling 2.7 MWh per year. The purchase of a composting machine that can compost up to 100 kg per day costs €12.500, when bought at the company TOGO. The final compost can be used for own gardening or sold for €70,- per cubic meter (TRUIC, 2021).

11.2. Future Irmão waste management

For the concept of the *Future Irmão Scenario*, it was decided to implement a biogas plant in the design. In particular, the type of fixed dome biogas plant, as shown with all parts in figure 11.2.

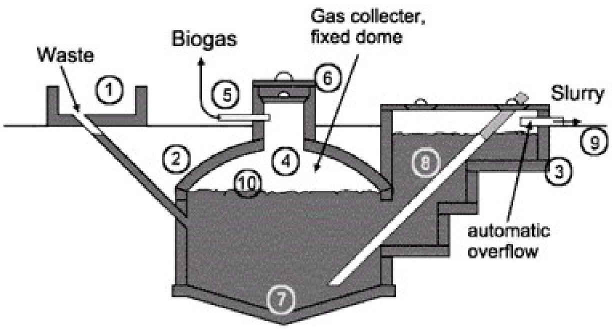

Figure 11.2: Fixed dome biogas plant (Radtke, 2016)

The operating principle of the fixed-dome biogas plant is based on anaerobic digestion. This is achieved by converting organic waste and human manure, which are collected by the vacuum toilet explained in section 8.1.2, to biogas and slurry via anaerobic digestion. Compared to the composting machine, human manure is thus added to the 12.5 tonnes of organic waste already produced. This amounts to an estimated 20 tonnes of waste that can be used by the biogas plant, according to (T. Degermann, personal communication, September 10, 2021). This results in the same emissions of 2.8 tonnes of CO_2 and 190 kg of CH_4 on a landfill, because the emissions of human manure are negligible. When using a fixed dome biogas plant, 2.34 tonnes of CO_2 and 148 kg of CH_4 emission can be avoided. This represents a saving of 83% in CO_2 and 79% in CH_4 emissions. In addition, energy is generated in the form of biogas (CH_4). The production of biogas would amount to 1050 m^3 per year, which is equivalent to 7.5 MWh. This is the same as 13 propane bottles of 45 kg, which are used now. This gas could then be used to power the gas heaters, which would run for approximately 330 hours. Furthermore, the approximate size of the biogas plant is 6m^3 with a installation and construction cost of €15.000 , according to a similar study (Castro-GonzÃ et al., 2015). The maintenance costs are €120, as indicated in section 8.2.2.

11.3. Underground waste container

As indicated in section 10.3, the solution of underground waste containers has been chosen for the problem of loose waste in the car park. This solution is used for both the *Improved Irmão Scenario* and the *Future Irmão Scenario*. Above the ground there will be a small container, into which the waste can be thrown per bag, see figure 11.3. Below ground is the storage of these bags until they are collected by the waste collection service.

The containers will be shared with the other 2 beach restaurants at praia do Castello, so the amount of waste will also be about 3 times as much. Together with the fact that the residual waste is collected almost daily and the other types of waste every other week, this results in a size of 5 m^3 per waste con-

Figure 11.3: Underground waste container (VConsyst B.V., 2021)

tainer. According to the company VConsyst, the costs for a container are €7,500 and the installation another €5,000. This results in a price of €12,500 per underground waste container. If the choice is made to deposit all 4 types of waste in an underground waste container, the total cost will be €50,000. Arrangements still need to be made with the local waste collection service, as they need to use the correct equipment to empty the containers. Furthermore, according to (T. Degermann, personal communication, September 10, 2021), Irmão can come up with a plan to the local government to finance it. This is already happening in the city of Lisbon.

11.4. Summary of the worked out waste management scenarios

In this chapter, the two concepts of waste preservation have been discussed. For the concept of *Improved Irmão Scenario* the composting machine is implemented. For the concept of *Future Irmão Scenario* the biogas plant is implemented. In both concepts, the solution of the underground waste containers returns, as this remains a problem to be solved in both cases. An overview of the concepts with their corresponding specifications is given in table 11.1.

Table 11.1: Overview of specifications different concepts per year.

	Emission (ton)	**Emission savings (ton)**	**Emission reduction (%)**	**Energy consumption (MWh)**	**Energy generation (MWh)**	**Cost**
Current situation (landfill)	2.8 CO_2, 0.19 CH_4	-	-	0	0	-
Improved Irmão	0.54 CO_2, 0.043 CH_4	2.26 CO_2, 0.147 CH_4	80% CO_2, 79% CH_4	2.7	0	€12.500,-
Future Irmão	0.46 CO_2, 0.042 CH_4	2.34 CO_2, 0.148 CH_4	83% CO_2, 79 % CH_4	0	7.5	€15.000,-
Underground waste container	-	-	-	-	-	€12.500,-/ container

IV
Energy system

12

Energy system analysis

This chapter aims to address the current state of energy supply and energy consumption at Irmão to determine where improvements can be made to become more sustainable. First, section 12.1 presents energy infrastructure in Portugal. Hereafter, section 12.2 provides an overview of the current energy infrastructure of Irmão to have a clear understanding of the type of energy sources used at Irmão. Then, section 12.3 presents a method to analyse the annual energy consumption based on a combination of the cover model and a created regression, called the *Regression model*. Subsequently, Section 12.4 then presents another method to evaluate the annual electricity consumption by using the *Electrical device model*. Hereafter, section 12.5 covers the gas consumption of Irmão. Finally, in section 12.6 a summary of the energy system of Irmão is made.

12.1. Energy infrastructure in Portugal

The total energy supply available for usage in a country is called the Total Primary Energy Supply (TPES). The TPES indicates how much energy is supplied by different energy sources, as shown in figure 12.1. In 2020, Portugal had a total energy supply of 231.2 TWh. Only 28.1% of the total Energy supply of Portugal came from renewable sources. This implies that Portugal depends mainly on non-renewable forms of energy for its total energy needs. In terms of non-renewable energy sources, Portugal is currently most dependent on oil (42.1%), natural gas (26.0%) and coal (2.9%). (IEA, 2021)

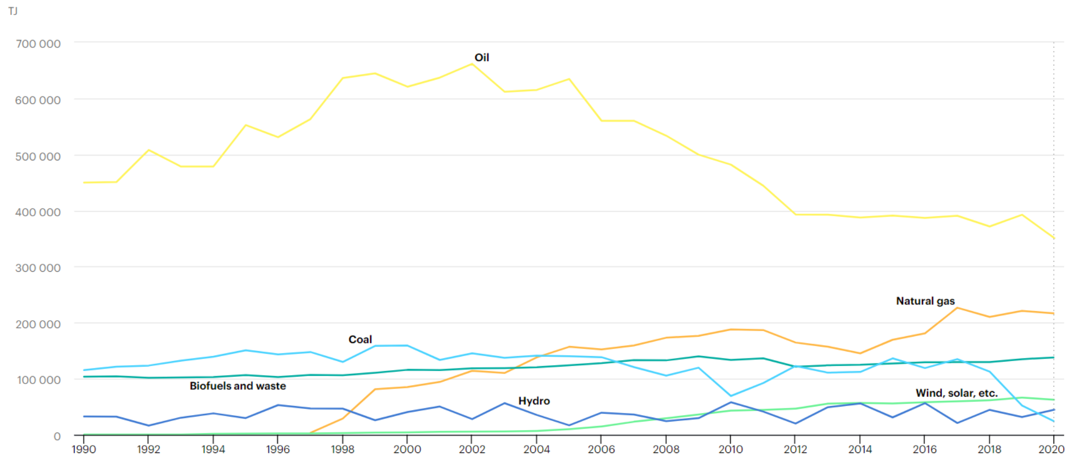

Figure 12.1: Total primary energy source of Portugal in TJ (1990-2020) (IEA, 2021)

Portugal has several renewable energy sources. The main contribution comes from biofuel and waste (16.6%). A significant part comes from wind (6.2%) and hydro (5.4%) energy. Finally, there is a relatively low share of other renewable energy sources such as, solar and geothermal (0.9 %). According to the Energy Policy Review done by the International Energy Agency (IEA, 2021), Portugal's renewable energy supply from 2000 until 2020 increased by 26% to a total of 28% of the total final energy consumption (TFEC). This is equal to 4.4 million tonnage of oil equivalent (Mtoe). In comparison with other IEA member countries, Portugal is ranked eighth as shown in figure 12.2.

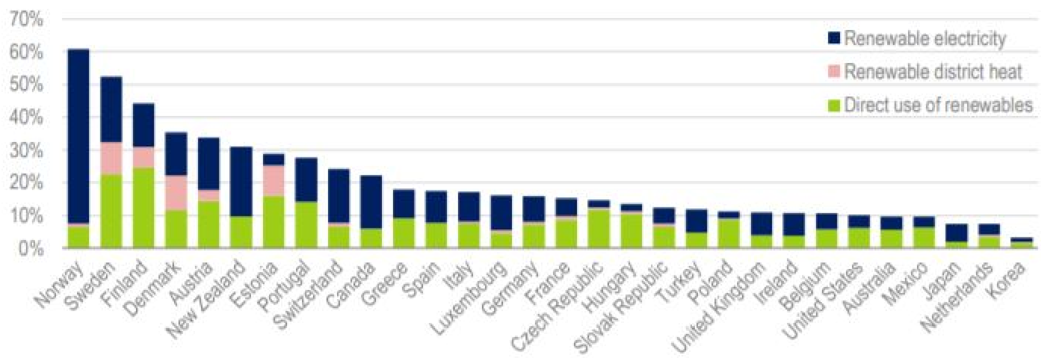

Figure 12.2: Ranking countries share renewable energy in total energy consumption 2019 (IEA, 2021)

The increase in renewable energy supply is mainly caused by a large increase in the installed capacity of wind energy, as shown in figure 12.3. Despite the progression in the total amount of installed solar cells, the low share of solar energy in the total renewable energy supply is remarkable. Most of the renewable energy generated is used in the form of electricity. Currently, 54.0% of the total electricity consumed, originates from renewable generation. This renewable electricity is generated by different kinds of renewable sources, which can be seen in figure 12.3. The other 46.0% of the electricity is produced by non-renewable means. The total grams of CO_2 emission of electricity comes down to 241 grams per kWh (APREN, 2019).

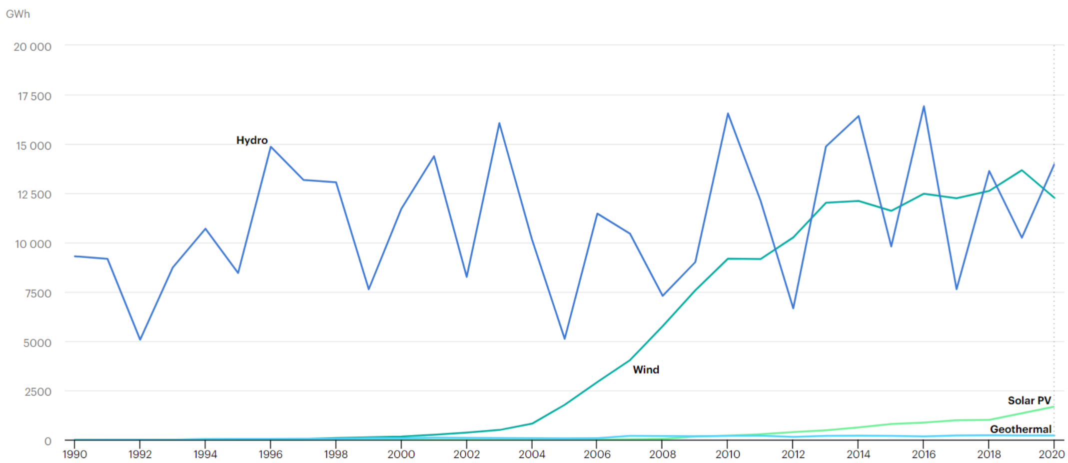

Figure 12.3: Electricity generation by renewable source in Portugal in GWh (1990-2019) (IEA, 2021)

Regarding the future, Portugal set renewable energy share targets in terms of gross final energy consumption, electricity, heating and cooling and transport. This was done in order to meet the EU climate goals for 2050. The targets to meet are that the shares of renewable energy in the gross final energy consumption for 2040 and 2050 are respectively 71 - 72% and 86 - 88% (IEA, 2021).

Besides the amount of emissions, the price per kWh of electricity is relevant. Electricity prices in Portugal are average compared to other European countries as depicted in figure 12.4. An attentive eye will notice that the price in Portugal depends mainly on the relatively high taxes that have to be paid. These taxes nearly double the price of electricity (46% of total price). Only Denmark (66%), Germany (53%) and Finland (47%) pay higher shares of taxes for electricity. The relative high level on taxes are result of energy policy options which account for 27% of the final price (ERSE, 2019). The costs of electricity generation are, on the other hand, relatively low compared to other European countries.

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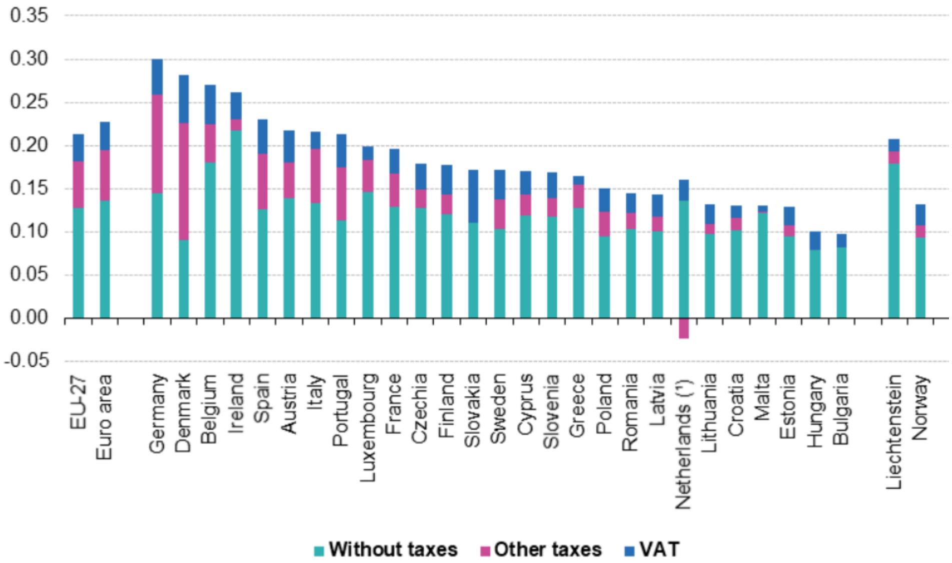


Figure 12.4: Average electricity prices in Europe of consumers smaller than 2.5 MWh per year in EUR/kWh in the second quarter of 2020 (Statista, 2021)

12.2. Energy infrastructure of Irmão

To be able to make Irmão more sustainable in terms of energy, it is important to have a clear overview of the current energy infrastructure of Irmão. In figure 12.5, a schematic overview of the current energy infrastructure of Irmão is given. Here it can be noticed that the energy sources of Irmão are the electricity grid and gas tanks. The local electricity grid provides energy in the form of electricity to all of the electrical devices. The gas tanks provide energy in the form of heat to three gas devices. This section will provide an overview of the current energy infrastructure of Irmão without the annual electricity and gas consumption. The annual electricity and gas consumption are provided in section 12.3 and 12.5 respectively.

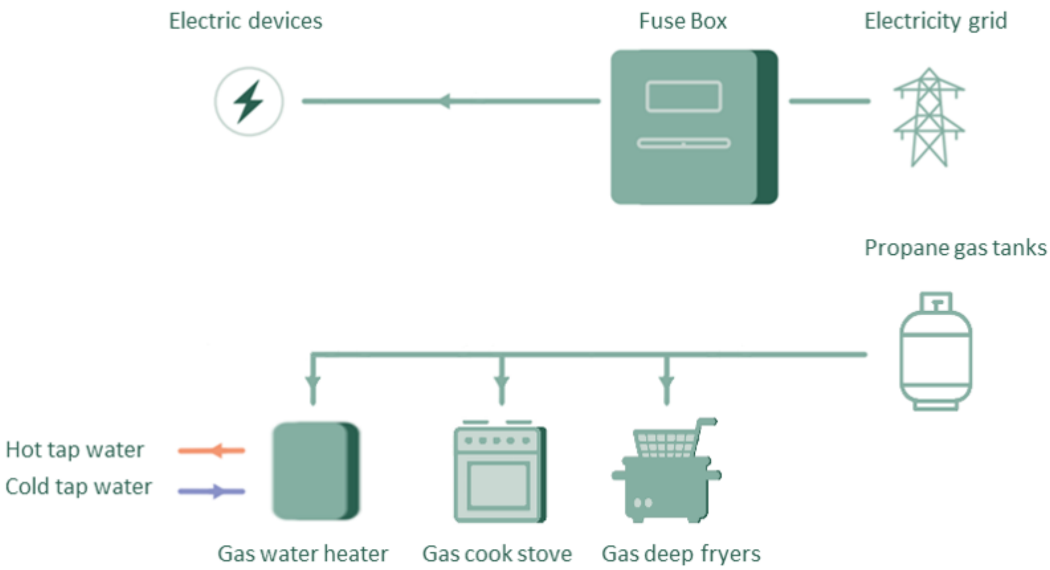


Figure 12.5: Schematic representation of the current energy infrastructure of Irmão

12.2.1. Electricity infrastructure of Irmão

Irmão is connected with the local electricity grid, which is maintained by the local electricity company EDP Comercial. In order for the electricity system to connect properly to the Portuguese grid, the characteristics of the Portuguese grid need to be identified. The standard voltage in Portugal is 230 Volts and the frequency of the grid is 50 Hz. Irmão has three connections to the local electricity grid to be able to meet the required electricity demand. Every connection of Irmão has a maximum current of 60 Ampere. This results in a power supply of 13.8 kW considering a voltage level of 230 V. The total maximum power supply from the grid is now calculated to be 41.4 kW. The devices are distributed over the three different electricity groups, because all the devices of Irmão combined require relatively high total power. As can be seen in figure 12.5, the electricity grid is connected with the electrical devices through the fuse box. In the fuse box, the electricity from the grid is distributed to all the electrical devices of Irmão. In section 12.3, a full overview of the annual electricity consumption will be elaborated.

Regarding the cost of electricity, Irmão has a specific contract with EDP. Irmão has a three hour daily electricity contract with EDP Comercial. EDP Comercial uses three different hourly tariffs for electricity. These are based on the time of consumption. The three tariffs are called Vazio, Ponta and Cheias meaning empty, tip and flood respectively. In figure 12.6, the tariffs distribution is given. A difference is made between summer and winter period. The prices Irmão pays during Vazio, Ponta and Cheias are 0.0792 €/kWh, 0.289 €/kWh and 0.1461 €/kWh respectively. In the period from 20 April 2021 to 21 July 2021, the tariff distribution of the electricity use of Irmão is known. This showed that 24% of all the electricity was consumed during Vazio tariff, 21% during Ponta tariff and 55% during Cheias tariff. This distribution is used for the whole year to estimate the total electricity cost during one year. The distribution is representative for Irmão, because this distribution is made over a relative large period of three months. Based on the given cost distribution, the average cost per kWh is calculated to be €0.160777.

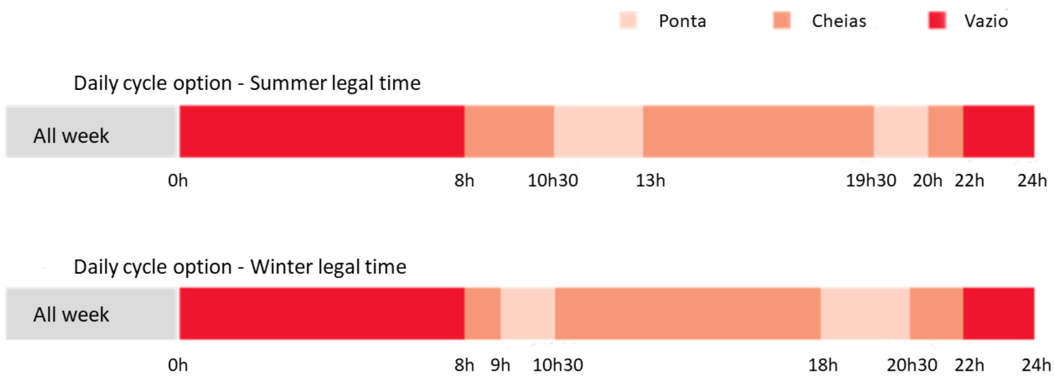


Figure 12.6: The daily cycle of the three hour tariff distribution for the summer legal time and thee winter legal time (EDP, 2021)

12.2.2. Gas infrastructure of Irmão

Besides electricity, a significant share of energy is supplied by gas. The gas used at Irmão is UN1965 propane gas. UN1965 propane is a mixture which exists for 90% of propane and 10% of butane. Propane is widely used as energy carrying gas in restaurants as it is relatively safe to use. This is due to the fact that contains no toxic elements and it is easy to transport in large tanks under pressure (Wang et al., 2021). Besides, propane is a by-product of natural gas processing and petroleum refining (Clough, 2014), which results in a relatively low climate impact when producing propane (Nolan, 2011). However, the burning of propane gas is not defined as sustainable as the burning of propane results in the emission of carbon dioxide (CO_2).

The propane gas Irmão uses is delivered in 45 kg tanks and can be easily connected to the gas pipelines of Irmão. In figure 12.5, it can be seen that Irmão uses gas for the gas water heater, the gas cook stove and the gas deep fryers. The reason Irmão uses a gas cook stove is that the chefs in the kitchen prefer to work with a gas cook stove, as this is the most comfortable way for them to work. The reason that Irmão uses a gas water heater and gas deep fryers is that the current existing connections to the local electricity do not provide enough power to supply an electric water heater and electric deep fryers with electricity. In section 12.5.3, a full overview of the current gas consumption will be elaborated. The cost of a propane gas tank is €74.50. This value is used further in this report to calculate the annual gas cost.

12.3. Electricity consumption based on the regression model

As mentioned in chapter 5, Irmão has not been open for a full year and therefore data on annual electricity consumption is lacking. For this reason, data from existing energy invoices and measured data are combined to produce a second-degree regression that relates the number of kWh of electricity consumption against the number of covers.

12.3.1. Electricity invoices

In Portugal, due to a shortage of personnel at the electricity suppliers to measure all electricity levels, payment for the consumption of electricity is based on estimates (Valbuena, 2018). Measurements are taken during a week and a consumption pattern is then drawn up for the following period. The length of a period is arbitrary. After this period has passed, the electricity level is measured again in order to determine the actual consumption of the period in question. If this consumption is higher than expected, an additional payment must be made. If the consumption was lower than expected, the money will be refunded (Valbuena, 2018). Because the consumption shown on the present bills is estimated, this data is unusable for mapping the electricity consumption.

However, the measured values on which the estimates are based can be used. In the past 7 months, 3 of these measurements have been carried out. The number of covers for these periods is also known. These consumption amounts are shown in table 12.1.

Table 12.1: Covers and electricity consumption from invoices for 3 different weeks.

From	Till	kWh	Cov
21-jul	27-jul	1856	1800
21-aug	28-aug	2208	1987
29-aug	3-sep	2426	2050

12.3.2. Electricity measurements

To gather more data on the electricity consumption of Irmão, measurements were taken. By noting the meter readings before the restaurant opens (12:30), the amount of electricity used the previous day is obtained. Also the number of covers is being monitored by the owner and therefore known over these intervals. In total, data has been collected over 5 weeks. Table 12.2 presents a summary of this. Table C.2 in the appendix lists all measurements.

Table 12.2: Covers and electricity consumption from measurements for 5 different weeks.

From	Till	kWh	Cov
6-sep	12-sep	2051	1782
13-sep	19-sep	1851	1670
20-sep	26-sep	2137	1692
27-sep	3-okt	1828	595
4-okt	10-okt	983	336

12.3.3. Regression

By combining the data from the invoices and the self-measured data, the electricity consumption and the number of covers are known for a total of 8 weeks. From these data points, two regressions are constructed. The first regression is of the first order and the second regression is of the second order. Together with the data points, they are presented in figure 12.7. The regressions are done for the number of covers in relation to the electricity consumption for a full week. The choice to use weekly consumption, as opposed to daily consumption, results in the fact that there are fewer measured data points available. However, this data is better compatible with the weekly number of covers, as presented in section 5.

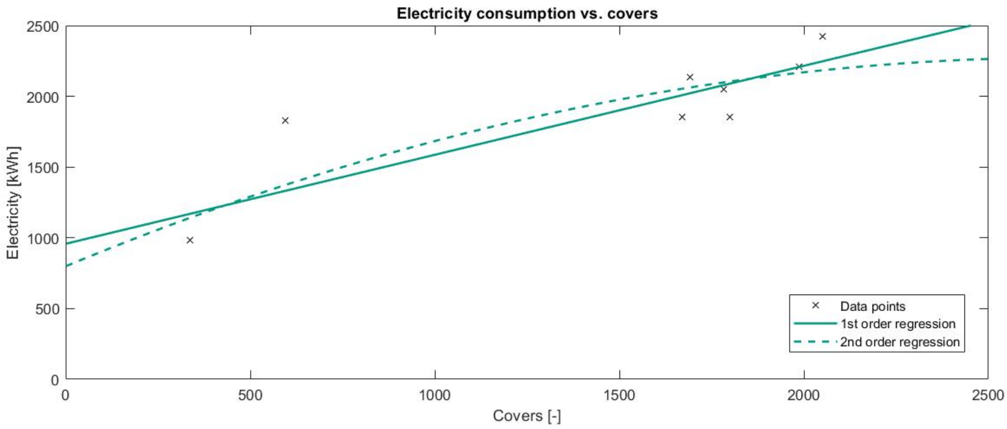


Figure 12.7: First and second order regression of the covers versus electricity consumption based on invoices and measurements

In order to determine which regression is the most representative, the R^2 and RMSE are examined. The R^2 values are 0.788 and 0.794 for the first and second order regressions, respectively. Subsequently, the RMSE values are 663.8 and 653.7 for the first and second order regressions, respectively. Although the R^2 and RMSE values are slightly more favourable for the second-order regression, the difference is too small to conclude which regression corresponds best to the supplied data. Since the R^2 and RMSE values do not allow for a definitive answer as to which of the two regressions is more representative, the course of these two regressions is examined from a physical point of view.

A characteristic of a first-order regression is its linear progression. This implies that the total number of extra covers has no influence on the marginal extra electricity consumption. Characteristic of the second order regression is the negative convexity. This implies that the marginal electricity consumption is higher at a lower number of covers than at a high number of covers. In other words, an extra cover at a low total number of covers results in a higher extra consumption of electricity than an extra cover at a high total number of covers.

As can be seen, at a high number of covers, the electricity consumption barely increases. This is in relation with the total number of customers Irmão can place in her restaurant. As mentioned before, it is not known what a specific cover is (one drink or a diner for 12 persons), but it is known that Irmão can not place an infinite number of customers in the restaurant and provide them with food. Above a certain amount of covers, it is therefore assumed that these covers are only drinks that are ordered for consumption on the beach. The electricity consumption for serving these drinks is significantly lower than for preparing a full meal, hence the low increment. It is therefore assumed that the second order regression is a better representation of reality.

It should be noted that the regression model should not be considered as the absolute truth and is only used as a tool for this study. Due to the lack of data and the origin of the available data, the regression is not perfectly accurate.

12.3.4. Annual consumption based on regression

By combining the weekly number of covers obtained in chapter 5 and the regression model from section 12.3.3, it is now possible to estimate the annual consumption of electricity. The findings are plotted in figure 12.8. On the left y-axis the number of covers is presented, on the right y-axis the weekly electricity consumption is presented and on the x-axis the weeks of the year.

The figure clearly demonstrates that the amount of electricity consumed does not increase significantly with the number of covers during the peak months from the 30th week of the year onwards. This is as expected as it is assumed that the total floor capacity is reached and only extra beverages are

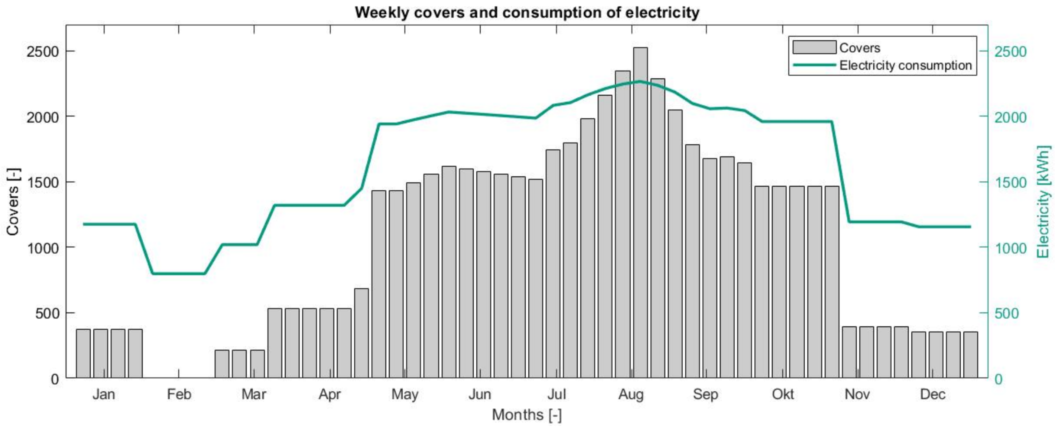


Figure 12.8: Direct translation from covers to electricity consumption per week

served on the beach . The total electricity consumption is calculated by summing the weekly electricity consumption. Based on the regression, the annual consumption is estimated to be 83.9 MWh.
The regression used is considered to reflect an accurate electricity consumption for the majority of the year. However, for weeks 5 to 9, it is estimated in advance that the displayed values will not be representative. In weeks 5 to 9, the restaurant is completely closed. It is therefore arranged in advance that the supplies are consumed. This ensures that all but a few machines can be closed down. Only the exterior lighting and alarm systems will remain on. This ensures very low consumption, which is currently not well reflected in the figure. Figure 4 will be manually adjusted for this reason. The consumption in these respective weeks is estimated at 40 kWh per week. This new adjusted plot is shown in figure 12.9.

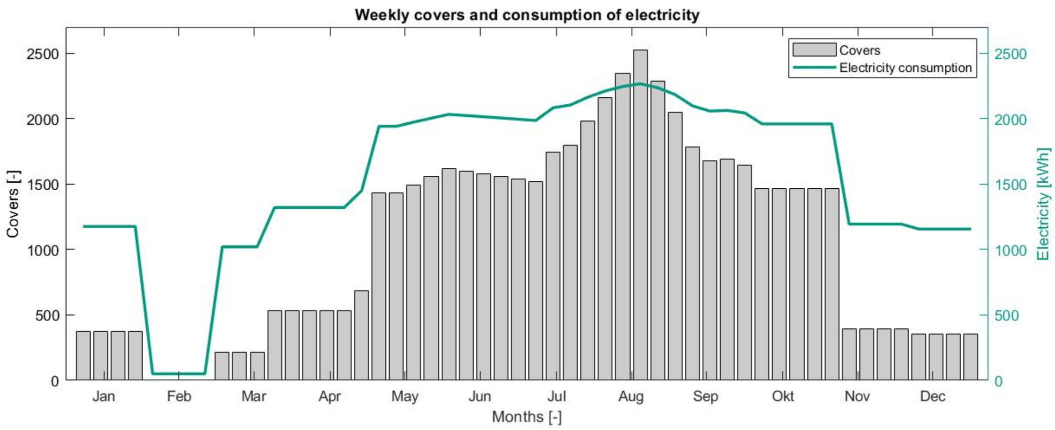


Figure 12.9: Adjusted translation from covers to electricity consumption per week

The total annual electricity consumption for the modified figure is estimated at 80.9 MWh. Literature studies estimate a similar restaurant to consume between 70 and 90 MWh depending on location and human influences such as careful use of appliances (Almeida, 2018).

12.4. Electrical device model

In section 12.3.3, an estimation of the electricity consumption is made with the regression model. In order to compare the regression model and due to the lack of complete data about the electricity consumption of Irmão, an attempt was made to create a model that can provide insight into electricity consumption, maximum power and the cost of electricity consumption. The model, called the *Electrical device model*, is created using the maximum power data of the electrical devices, the amount of electrical devices and the assumptions presented in Appendix C. It is important to have an insight in the electricity consumption, maximum power and electricity cost to be able to design a new energy system of Irmão. The *Electrical device model* will be described in this section. In figure C.1,C.2 and C.3 of Appendix C, the *Electrical device model* is shown. In this model, the maximum power, electricity consumption and electricity costs are estimated. The electricity consumption and the maximum power are important, as the new designed electricity system must meet the electricity demand and maximum power requirement. The costs are important to compare new energy system designs with the current situation. The *Electrical device model* consists of three parts. First the power requirement is determined. Hereafter, the electricity consumption is estimated and finally the electricity costs of Irmão are calculated. The obtained values are rough estimations and are used to provide an overview of the power requirement, electricity consumption and the electricity costs.

12.4.1. Required power

The reason that the maximum power of Irmão is calculated relates to their connection to the local electricity grid and to the new electricity system design. As mentioned in section 12.2.1, the maximum power supply from the electricity grid is 41.4 kW divided over three connections with the local electricity grid. To determine the required power of Irmão, the power specifications of all electrical appliances of Irmão are collected in the *Electrical device model*. The restaurant uses many different electricity-consuming devices for lighting, preparing food and running the restaurant, among other things. In the model, it can be seen that Irmão has around 70 electrical devices, as well as lighting in each area. The owner of Irmão did not allow us to measure the current for all the electric devices to calculate the power per device, as this would make work in the restaurant impossible. Therefore, it is decided to measure three devices of which a large consumption is expected, because this would cause less interference. The theoretical maximum power of the remaining electrical devices are obtained from the manufacturers. The theoretical maximum power value per electric device is used to determine the total maximum power of Irmão. The theoretical total maximum power of Irmão is 60.86 kW. This is much higher than the available 41.4 kW of the grid. This can be explained by the fact that no electrical device reaches its maximum theoretical power when in use. The theoretical maximum power indicates the power to which the device could be operated. In practice, however, it often turns out that when the device is used to its maximum capacity, this is not achieved. This finding was confirmed by measuring three electrical devices of Irmão. The three devices are given in table 12.3, with their specific maximum theoretical and practical maximum power requirement.

Table 12.3: Electrical current (Ampere) measurements and power calculations of the extractor, electrical baking tray and electrical pizza oven.

Device	**Maximum Theoretical Power (W)**	**Measured current (Ampere)**	**Calculated practical Power (kW)**
Extractor	0.45	1.5	0.345
Electrical baking tray	15	32.1	12.8
Electrical pizza oven	15.6	37.8	15.1

The practical power of the electric pizza oven and the electrical baking tray are calculated with equation 12.1, which is the 3-phase power equation. In this formula, V is the voltage of 230 V, I is the current measured and $\sqrt{3}$ is the specific factor for the 3-phase formula. The current is measured with an ampere meter. The power of the extractor is calculated with equation 12.2, which is the power equation for a single phase system. In this formula, V is the voltage of 230 V and I is the current measured. The measured power of the electrical pizza oven and the electrical baking tray are 97% and 85% of their maximum. Both the devices have a very high power consumption when working on full power. In reality however, the devices almost never operate at full power. The extractor, for example, has a measured power of 77% of its theoretical power.

$$P = V * I * \sqrt{3} \tag{12.1}$$

$$P = V * I \tag{12.2}$$

The measured power of the three electrical devices provide an indication of the practical maximum power of an electrical devices. In the *Electrical device model*, an assumption is made of the practical power of all the electrical devices of Irmão. For this estimation, it is assumed that the practical power is

80% of the theoretical power for all the devices except for lighting and the measured devices. The value of 80% is used, because this provides a reasonable safety margin for power ratings of the electrical devices (Patel, 2017). Lighting is operating at constant maximum theoretical power (Almeida, 2018). The practical maximum power of all the electric devices of Irmão combined is calculated to be 52.27 kW. The calculated practical total maximum power is much higher than the 41.4 kW available maximum power of the electricity grid. However, the electricity system of Irmão works properly. This can be explained by the fact that the devices never operate at their maximum power. In addition, it is noticeable in the model that especially devices that generate heat have a high maximum power. This is explained by the fact that generating heat requires a large amount of energy (Kubba, 2017). However, Irmão does need heat generating devices to prepare dinner.

12.4.2. Electricity consumption

The second part of the *Electrical device model* relates to the electricity consumption of Irmão. The electricity consumption is determined by combining the estimation of the power requirement of Irmão in section 12.4.1 with an estimation of the hourly use of the electrical devices. For the hourly use of the electrical devices, a difference is made between a fully opened day, a semi-closed day (when the restaurant is closed but staff is present) and a day when the restaurant is fully closed. For the three different type of days, assumptions are made for the amount of hours the electrical devices are turned on. For example, on a semi-closed day, when employees are working, the cooling systems and lighting systems are still on. When Irmão is fully closed during February, all the devices are turned off, except for the night lighting. The estimated electricity consumption for a fully opened day is 305.61 kWh/day. For a semi-closed day this is 135.67 kWh/day and for a fully closed day this is only 0.8 kWh/day. These estimations are based on the amount of hours a device is turned on and the practical power of the device. The estimations can be found in table C.1 and table C.2 of Appendix C. To calculate the yearly electricity consumption, a distribution is made over the quantity of the three types of days. The total calculation is based on 28 days fully closed, 68 semi-closed days and 269 days fully open. The 28 days fully closed is based on the four weeks in February, the 68 semi-closed days is based on the 48 remaining Mondays and an assumed amount of 20 days when the restaurant is semi-closed due to the weather. The total electricity consumption of Irmão is then summed up to an estimated 90.518 MWh/year.

The yearly energy consumption is distributed per device category. The categories with their devices are provided in table C.1 of Appendix C. The distribution of energy consumption per category is given in figure 12.10. Here it can be noted that cooking and refrigeration are the largest energy consumers which is compared to literature, a logical finding (Almeida, 2018).

12.4.3. Electricity cost and emissions

The third and last part of the *Electrical device model* estimates the electricity cost of Irmão. Irmão has a three hour daily electricity contract with EDP Comercial which is the local electricity company, as mentioned in section 12.2.1. This distribution is used for the whole year to estimate the total electricity cost during one year. The distribution is representative for Irmão because this distribution is made over a relative large period of three months. The total electricity cost of Irmão is estimated to be €14.420,32 per year when an annual total electricity consumption of 90.518 MWh is used. The three different hourly tariffs distribution could also be used together with the regression model. The total annual electricity consumption obtained from the regression model is 80.90 MWh. Using the three hour tariff distribution, a total electricity cost of €13.015,08 per year is calculated.

The CO_2 emissions from Irmão's electricity use are calculated by multiplying the average emissions from electricity generation in Portugal by Irmão's total electricity consumption. The average CO_2 emission per generated kWh is 241 gram as stated in section 12.1. When the total electricity consumption of 80.9 MWh from the regression model is used, a yearly CO_2 emission of 19.50 ton is estimated. When the total electricity consumption of 90.518 MWh from the Electrical device model is used, a yearly CO_2 emission of 21.82 ton is estimated.

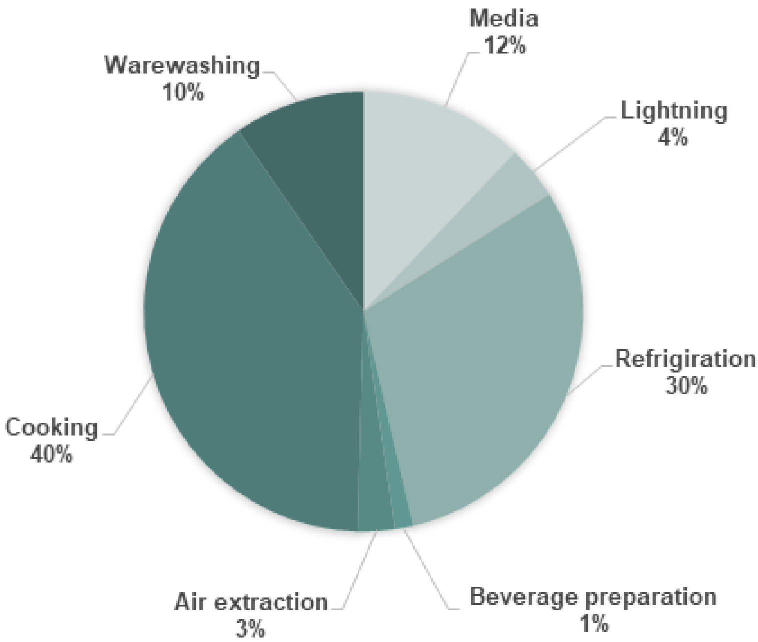


Figure 12.10: Electricity consumption distribution per category at Irmão.

12.5. Gas usage at Irmão

As mentioned in section 12.2.2, a significant share of energy is supplied by gas. The gas used at Irmão is UN1965 propane gas. UN1965 propane is a mixture which exists for 90% of propane and 10% of butane and an odorous gas. Propane has a heating value of 50.35 MJ/kg. Butane has a heating value of 49.50 MJ/kg (Linstrom, 1997). The energy produced by burning one kilogram of gas is calculated to be 13.3 kWh. The gas-fired devices are the gas water heater, gas cook stove and the gas deep fryers as explained in section 12.2.2.

12.5.1. Emissions from gas usage

During the operation of the gas-fired devices, emissions of CO_2 and NO_x occur. Burning one kilogram of UN 1965 propane, results in an emission of three kilogram of CO_2, according to the label on the gas tank. When the CO_2 emission per kilogram is divided by the energy generation from the burning of propane, a CO_2 emission of 0.226 kg/kWh is obtained. This is 6.23 % lower than the average CO_2 emission per kWh of the Portuguese electricity grid.

The burning of UN1965 propane in the gas range and the deep fryer do not lead to the emission of NO_x. This is because the flame temperature is too low to form thermal NO_x and there is no nitrogen in the gas to form fuel NO_x (van Ommen, 2021). However, the gas water heater does emit thermal NO_x as the temperature in a water heater becomes higher due to the insulated propane combustion. The gas water heater emits 39 mg NO_x/kWh according to the manufacture of the gas water heater used at Irmão (Volcano, 2018).

12.5.2. Total gas consumption

On average, Irmão uses one tank of 45 kilogram propane every five days they are opened. Taken into account the emission rate of burning propane, the consumption of gas leads to an emission of 27 kilogram CO_2 per day. The tanks are delivered by the local companies GALP and CESPA. When new tanks are delivered, empty tanks are picked up and are refilled by the local gas company. The cost of one tank is €74.80. In table 12.4, the average consumption and cost of propane per day, week and year together with the emission of CO_2 from the burning of propane per day, week and year are depicted. A standard week consists of six fully open days and an average year consists of 269 fully open days.

Table 12.4: The average gas consumption in (kg) and (kWh) per day, week and year is provided. Besides and cost of propane per day, week and year together with the emission of CO_2 from the burning of propane per day, week and year is given.

Period	Consumption propane (kg)	Energy consumption of propane (kWh)	Emissions CO_2 (kg)	Cost (euro)
Day	9.0	119.48	27.00	€ 12.47
Week	54.0	716.85	162.00	€ 74.82
Year	2,421.0	32,138.78	7,263.00	€ 3,354.43

12.5.3. Gas consumption per device

When calculating the maximum propane consumption per gas device, it is important to consider the efficiency of the device to calculate the effective power. The effective power is the power that is ultimately used to heat up the food or water. With this information, the maximum propane consumption per gas device is calculated below.

- The gas range consists of six gas burners and has a power of 27 kW. The standard heat transfer efficiency of a gas range is around 40% (Sweeney et al., 2014). This leads to a maximum total effective power of 10.8 kW. The propane gas consumption is 2.03 kg per hour and a CO_2 emission of 6.09 kilogram per hour.
- The two deep fryers are from the brand Magnus, type FG2X20M and have a maximum power of 28.00 kW combined. The efficiency of a gas deep fryer is assumed to be 50% (*Commercial Fryers Key Product Criteria*, 2016). This leads to a maximum effective power of 14% kW. The maximum propane use is 2.11 kg per hour and a CO_2 emission of 6.33 kilogram per hour.
- The Volcano gas powered water heater has a maximum power of 24.1 kW (Volcano, 2018). The efficiency of a gas water heater is stated to be 75% (Tajwar et al., 2011). This leads to a maximum effective power of 18.075 kW. The maximum propane gas consumption is 1.82 kg per hour and a CO_2 emission of 5.46 kilogram per hour.

In table 12.5, an overview of the daily and annual propane usage per gas device is provided in two tables. In this table, the share of daily and annual propane consumption per device is given. Besides, the average daily and annual propane, CO_2 and NO_x emissions in kilograms are provided considering a daily propane consumption of 9 kg, when all the devices would operate at maximum power. The last row of each table gives the daily and annual energy consumption per device in kWh respectively. When the gas range, deep fryers and the water heater are operating at their maximum, a propane consumption of 6.45 kg per hour can be reached. Taking into account that the average gas consumption of Irmão per five open days is 45 kg, it can be concluded that the gas range, the deep fryers and the boiler are almost never operating at maximum power. In order to calculate the energy consumption in kWh per day, it is useful to know how long the gas devices can operate at maximum power. The time that the devices can operate at maximum power is calculated to be 1.4 hours per day.

Table 12.5: The average daily and annual share of propane consumption (%), propane consumption (kg), CO_2 emission (kg), NO_x emission (kg) and the energy consumption (kWh) per gas device estimated with the *Electrical device model*.

Daily	Gas range	Deep fryers	Water heater	Total
Share of propane consumption (%)	34.13	35.40	30.47	100.00
Propane consumption (kg)	3.07	3.19	2.74	9.00
CO_2 emissions (kg)	9.22	9.56	8.23	27.00
NO_x emissions (kg)	0	0	1.42	1.42
Energy consumption (kWh)	40.78	42.29	36.40	**119.48**

Annual	Gas range	Deep fryers	Water heater	Total
Propane consumption (kg)	826.38	856.99	737.62	2,421.00
CO_2 emissions (kg)	2,479.15	2,570.97	2,212.87	7,263.00
NO_x emissions (kg)	0	0	381.89	381.89
Energy consumption (kWh)	10,970.25	11,376.56	9,791.97	**32,138.78**

12.6. Summary energy analysis Irmão

The energy system of Irmão contains an electricity part and a gas consumption part. First the electricity system was analysed, secondly the gas system was reviewed. In table 12.6, the final values of the energy system overview are depicted.

The electricity system of Irmão is analysed with two different methods. The first method is the *regression model* and the second model is the *Electrical device model*. Both models estimate the electricity consumption of Irmão. The *Electrical device model* estimates a total electricity consumption of 90.518 MWh per year. The non modified *regression model* estimates a total electricity consumption of 83.9 MWh per year. The outcome of the regression model is modified based on physical assumptions such as the full closing in February. The modification of the regression model provides a new total electricity consumption of 80.9 MWh per year. Comparing the outcomes of the models, it can be noted that the results are relatively similar and in the same order of magnitude. The difference in estimated annual electricity consumption between the two models is attributed to the fact that the regression model includes seasonal occupation while the electricity model does not. Since the *Regression model* includes seasonality it was decided to use 80.9 MWh as a design parameter for the future electricity system.

The power requirement of Irmão is only estimated with the *Electrical device model* and is compared with the current local electricity grid connection. The theoretical total maximum power requirement of Irmão is estimated to be 60.86 kW. The practical total maximum power is calculated to be 52.27 kW. Comparing this value with the local electricity grid connection of 41.4 kW, it is concluded that the electrical devices are never used on their maximum practical power at the same time, as Irmão did not have power failures in the past year. Therefore, the 41.4 kW value can be used as a design parameter for the future electricity system.

The gas usage of Irmão is analysed and provides an insight in the type of gas, gas devices, gas consumption and emissions. The type of gas is the UN1965 propane. The gas devices are the gas range, the two gas deep fryers and the gas water heater. The total daily energy consumption of the gas devices is estimated to be 119.48 kWh/day. The estimated annual energy consumption of the gas devices is estimated to be 32.14 MWh/year.

The emissions of the energy system of Irmão are produced during the generation of electricity from the Portuguese electricity grid and the consumption of gas at Irmão. In table 12.6, the total emissions for electricity generation and gas consumption are given. The total CO_2 emission per year is 26,758.72 kg. The average CO_2 emission per kWh is 0.237 kg/kWh. The consumption of propane gas at Irmão does emit less CO_2 than the use of electricity of the Portuguese electricity grid. Regarding the emission of NO_x, Irmão has an emission 381.89 kg NO_x per year, caused by the gas water heater. Besides, the energy system of Irmão does not emit SOx. Regarding the sustainability of Irmão's energy system, great improvements can be made by reducing the given emissions of CO_2 and NO_x in Irmão's current energy system. This can be done by reducing the amount of energy used and by using energy sources other than gas and the local electricity grid.

The cost of the energy use of Irmão are given in table 12.6. The total cost of the electricity consumption is calculated for a total electricity consumption of 80.90 MWh/year. The total electricity costs of Irmão are € 13.015,08 per year. The total cost of the gas consumption is € 4.024,24 per year. The total energy cost of Irmão can then be calculated to be € 17.030,34 per year.

Table 12.6: Summary of the energy consumption, CO_2 emission, NO_x emission and cost of the energy system of Irmão.

Type of energy	**Energy consumption (MWh)**	**Emission CO_2 (kg)**	**CO_2 emissions per kWh (kg/kWh)**	**Emission NO_x (kg)**	**Cost (euro)**
Electricity	80.90	19,495.72	0.241	0	€ 13.006,10
Gas	32.14	7,263.00	0.226	381.89	€ 4.024,24
Total	113.04	26,758.72	0.237	381.89	€ 17.030,34

13 Energy system solutions

After identifying the total consumption of energy, the required power and the pollutants released by the use of energy in chapter 12, this chapter will focus on the possibility to decrease the energy consumption and the reduction of pollutants while using and generating energy. The energy consumption can be divided in electricity and gas consumption as explained in chapter 12. First the possibility to reduce the electricity consumption of Irmão will be elaborated in section 13.1. Hereafter, in section 13.2, the change from gas to electricity will be discussed. In section 13.3, the possible renewable energy sources will be evaluated. This will be done by comparing various ways in which renewable energy can be generated on micro level at Irmão. Finally, the energy system solutions are summarized in section 13.4.

13.1. Decreasing energy consumption

To make Irmão more sustainable in terms of energy, it is necessary to look at the option to decrease the energy consumption of Irmão. Decreasing the energy consumption can be done by replacing electrical devices with relative low efficiencies. Considering the fact that the Irmão started last year and purchased new equipment of good quality, it is considered that not enough sustainable progress could be made here compared to the cost of renewing one year old models of appliances.

Another way to make appliances operate more efficient is to carefully position specific electrical appliances. When a cooling system is placed next to an oven, for example, the efficiency of both is reduced by up to 30% (Almeida, 2018). According to the owner of Irmão, it was taken into account to not place heat producing devices close to cooling systems. This is checked and confirmed during the identification of all electrical devices at Irmão. Therefore little progress is to be made in the placement of all energy-consuming appliances.

13.2. Gas to electricity

The use of gas is, as explained in section 12.5, not sustainable because of the emitted CO_2 and NO_x. The gas devices can be replaced by alternate electric devices to take over the functions of the gas devices. In order to compare the CO_2 emissions of using gas and the Portuguese electricity grid, it is necessary to indicate how much energy is needed to run the alternate electric devices. The gas devices of Irmão are the gas range, the two deep fryers and the water boiler, as mentioned in section 12.5. The average daily gas consumption per device is given in table 12.5. The alternatives for the gas devices are given below. Included is a comparison about the difference in CO_2 emissions.

13.2.1. Cook stove

The gas range that is currently used can be replaced by an electrical or induction cook stove. The heat transfer efficiencies of a gas stove, induction stove or electric stove are 40%, 74% and 90% respectively (Sweeney et al., 2014). This would suggest that induction is by far the most sustainable option. However, when using an induction stove, it is only possible to use specific kitchen equipment. Many cooking equipment must be replaced, this will lead to high initial costs. Therefore, both the electric stove and the induction stove are worked out below. The current used gas range has an effective maximum power capacity of 10.8 kW. The induction cook stove and electric cook stove must therefore require a minimum effective power of 10.8 kW. Besides, the minimum required amount of hobs is six and the required average operating time of a gas device at maximum power is 1.4 hour per day as mentioned in section 12.5. The induction cook stove and the electric cook stove are also compared using the CO_2 emissions per day. The gas range has a CO_2 emission of 9.22 kg/day as mentioned in section 12.5.

- An *Induction cook stove* has an efficiency of 90%. Therefore, the required power capacity is 12.0 kW to reach an effective power capacity of 10.8 kW. The required power decreases by 55.6% when using an induction cook stove instead of the currently used gas range. The energy consumption of the induction cook stove will be 18.2 kWh/day. This leads to a CO_2 emission of 4.37 kg/day which is a reduction of 52.6% compared with the gas range.
- The efficiency of an *electric cook stove* is assumed to be 74%. To reach an effective power of 10.8 kW, the electric cook stove must have a power of 14.6 kW. This is compared to the 27.0 kW power of the gas range, a decrease of 45.9% in required power. Taking into account the operation time of 1.4 hours per day, the daily energy consumption of the electric cook stove is 22.05 kWh. This leads to a CO_2 emission of 5.31 kg/day which is a reduction of 42.4% compared to the gas range.

A multi criteria analysis is made to select the most suitable cook stove. The gas range, electrical cook stove and the induction cook stove are compared in table 13.1. The criteria are given together with their weight. The most important criteria are the cost, safety and environmental impact. Cost is very important because the restaurant is a relatively small company and therefore the investment possibilities are limited. Besides, the topic specific criteria safety has a high weight factor, because a cook stove can be very dangerous in a crowded kitchen and in terms of fire risks. Environmental impact is the most important, because the goal is to reach a higher level of sustainability and thus minimize the environmental impact. The second topic specific criteria is usability. Usability does not differs much for a gas cook stove or the electrical and induction cook stove which are powered by electricity. The gas cook stove is connected to separate gas tanks, which must be replaced when they are empty. The benefit of devices powered by electricity is that no additional actions need to be taken during cooking. However, the chef of Irmão personally finds this the most comfortable way to cook and therefore the devices have the same score. The gas cook stove scores low on environmental impact because of the relatively low efficiency. Besides, the gas cook stove scores low on safety due to the safety risk of gas. The electrical cook stove has a lower efficiency than the induction cook stove and therefore scores less on environmental impact. The induction cook stove scores relatively high on most criteria but especially on environmental impact due to the highest efficiency compared with the other devices. Therefore, the induction cook stove has the highest weighted score followed by the electric cook stove. The gas cook stove scored significantly lower. The conclusion is made that the induction cook stove is the most suitable option.

Table 13.1: Multi-criteria analysis of a gas cook stove, electrical cook stove and induction cook stove.

General criteria	**Weight**	**Gas**	**Electric**	**Induction**
Cost	4	4	5	3
Ease of implementation	2	3	5	4
Maintenance	2	3	4	4
Environmental impact	5	1	3	5
Esthetics	1	3	4	4
Lifetime	2	4	4	4
Topic specific criteria				4
Usability	2	4	4	4
Safety	4	1	3	5
Weighted total		**54**	**85**	**93**

13.2.2. Deep fryers

The gas deep fryers can be replaced by electric or induction deep fryers. The efficiency of an electric deep fryer is assumed to be 80% (*Commercial Fryers Key Product Criteria*, 2016) and of an induction deep fryer is 95% (Leadstov, 2021). The electric and induction deep fryers will be elaborated and compared with the gas deep fryer below. The gas deep fryer has an effective maximum power capacity of 14 kW. The size of the current gas deep fryer is 2x20 Liter. The electric and induction deep fryers are required to have an effective power capacity similar to the gas deep fryers and the size must be 2x20 Liter. Besides, the minimum required operating time at maximum power is 1.4 hour per day. The electric and induction deep fryers are also compared with the gas deep fryer on the basis of CO_2 emissions. The gas deep fryer consumes 3.16 kg propane gas per day. This leads to a CO_2 emission of 9.56 kg/day as mentioned in section 12.5.

- The efficiency of an *electric deep fryer* is assumed to be 80%. The electric deep fryer must have a power capacity of 17.5 kW to reach an effective power capacity of 14 kW. This is a decrease of 37.5% in required power compared with a gas deep fryer. The daily energy consumption of an electric deep fryer will be 24.43 kWh. This leads to a CO_2 emission of 6.37 kg/day which is a reduction of 33.4% compared with the gas deep fryers.
- The *induction deep fryer* has an efficiency of 95%. The induction deep fryer must therefore have a power capacity of 14.73 kW, to meet the required effective efficiency of 14 kW. The required power compared with the gas deep fryer is decreased by 47.4%. The daily energy consumption of the induction deep fryer will be 20.57 kWh. This leads to a CO_2 emission of 5.37 kg/day, which is a reduction of 43.9% compared with the gas deep fryers.

In table 13.2, a multi-criteria analysis of the different deep fryers is provided. It can be noticed that the induction deep fryer is not included in the multi-criteria analysis. The reason for this is that no induction deep fryer with two times 10 liter capacity can be found. Because this is a requirement for the deep fryers of Irmão, the induction deep fryer is not taken into account. In the multi-criteria analysis in 13.2, the large difference in total weighted score can be noticed. The electrical deep fryer does score better on almost all the criteria. The criteria Environmental impact, which is the most important in terms of sustainability, shows that the electrical deep fryer scores higher. This is because the electrical deep fryer has a much higher efficiency compared with the gas deep fryer.

Table 13.2: Multi-criteria analysis gas deep fryer and electrical deep fryer.

General criteria	**Weight**	**Gas**	**Electrical**
Cost	4	2	4
Ease of implementation	3	3	4
Maintenance	3	2	4
Environmental impact	5	1	3
Esthetics	2	3	4
Lifetime	2	4	4
Topic specific criteria			
User friendly	1	3	4
Safety	4	2	4
Weighted total		**53**	**107**

13.2.3. Water heater

Irmão does not require a central heating because the building is partly open. This makes heating the building a very inefficient operation. Therefore, the water heater must only produce hot water for water taps and the shower. The water heater can be replaced by an all-electric water heater or a heat pump. An all-electric water heater is similar to a gas water heater. The difference is that the boiler is powered by electricity. The water is heated by a system of pipes that are heated by electricity. A heat pump is an electric system that uses heat energy from an external heat source to heat or cool a heat sink (Kozai and Niu, 2020). A difference is made between the air-water heat pump, the water-water heat pump, the solar thermal heat pump and the geothermal heat pump (Urchueguia, 2016). The efficiency of a standard gas water heater is assumed to be 75%. This leads to an effective efficiency of 18.075 kW. The gas water heater heater consumes 3.16 kg propane gas per day, which leads to a CO_2 emission of 8.23 kg/day as mentioned in section 12.5.

The efficiency of an electric water heater is assumed to be 90% (Balke et al., 2016). The efficiencies of different heat pumps depend on many factors explained below. Important to notice is that the efficiency of a heat pump is normally given in a Coefficient of Performance (COP) value. A COP of 1.0 means that for every obtained kWh of heat, 1.0 kWh of electricity is used to operate the pump. The COP value of a heat pump depends on the chemical specifications of the fluid in the system and of the temperature of the medium outside the pipe system of the heat pump. The COP value of a heat pump mostly varies between a lower and upper bound. A COP value can be for example between 2.0 and 5.0. This means that the efficiency of the heat pump is between 200% and 500%. For the heat pumps explained below, the average COP value will be used to calculate the CO_2 emission reduction of using an alternative for the gas water heater.

This CO_2 reduction estimation is not sufficient to calculate the CO_2 emission reduction of using a specific type of heat pump instead of a gas water heater for a full year. The reason for this insufficiency is that temperature of the chemical fluid in the heat pump system depends on many factors and the COP value is different for different chemical fluid temperatures. However, the average calculation gives an indication of the efficiency of a heat pump. Below, an overview of the different alternatives for the gas water heater are provided.

- The efficiency of an *all-electric water heater* is assumed to be 90% as stated above. When an effective power capacity of 18.075 is required, a power capacity of 20.08 kW is sufficient for the electric water heater. This is a decrease of 16.7% in required power. The daily energy consumption of the all-electric water heater will be 30.33 kWh. This leads to a CO_2 emission of 7.31 kg/day which is a reduction of 11.2% compared with the gas water heater.

- The *air-water heat pump* uses heat from the outside air to heat up water in a pipe system. The water is then led into an insulated water tank. In an air heat pump, the electricity is only used to operate the evaporator fan and compressor when heating the water. The air-water heater is relatively easy to implement because the evaporator fan can be placed just outside the restaurant. An air heat pump normally has a COP value between 2.0 and 4.0 (Dincer and Rosen, 2021). This leads to an average COP of 3.0 and an efficiency of 300%. The energy consumption of the air-water heat pump is then 9.12 kWh/day. This leads to a CO_2 emission of 2.20 kg/day which is a reduction of 73% compared with the gas water heater.

- The *water-water heat pump* uses heat from water for heating water in the insulated water tank. A pipe system is led trough water with a specific temperature. A chemical mixture is pumped through this pipe system to extract heat to heat up the water. Electricity is used to pump the chemical mixture through the pipe system. The efficiency of a water-water heat pump depends largely on the difference in temperature between the chemical fluid and the water where the pipe system is placed.

  The COP value of a water-water heat pump normally varies between 3.0 and 5.0 (Dincer and Rosen, 2021). This leads to an average COP value of 4.0. Taking into account an efficiency of 400%, an electricity consumption of 6.83 kWh/day is estimated for water-water heat pump. This leads to a CO_2 emission of 1.65 kg/day which is a reduction of 80% compared with the gas water heater.

  At Irmão, an option would be to have a pipe system in the sea to subtract heat from the sea and heat up the water in the insulated tank . A great disadvantage is that the system requires a lot of maintenance (Urchueguia, 2016). Besides, at Irmão, the system must be constructed in the dune area and the strong Atlantic Ocean. This requires a strong foundation and building in the protected dune area is forbidden by the local government.

- A *solar thermal water heat pump* uses heat from solar radiation for heating water or a chemical fluid in a pipe system which is exposed to solar radiation. Electricity is only used to pump water or the chemical fluid through the pipe system. The hot water is stored in a insulated tank similar to the standard gas boiler or the chemical fluid is used to heat the water in the insulated tank.

The solar thermal pipe system can be placed on any convenient place. To give an insight in the efficiency of the solar thermal heat pump, a rough estimation is made for the solar thermal heat pump at Irmão.

The COP value of the solar thermal heat pump depends on the chemical fluid temperature. The chemical fluid is heated by the sun and outside temperature. According to Volthera (Volthera, 2021), the COP value is between 2.2 and 4.0 when the water must be heated to 55°Celsius. This leads to an average COP value of 3.1. Taking into account an efficiency of 310%, an electricity consumption of 8.82 kWh/day is estimated for the solar thermal heat pump. This leads to a CO_2 emission of 2.13 kg/day which is a reduction of 74% compared with the gas water heater.

A relatively new and promising option is the combination of Photovoltaic solar panels and the solar thermal water heat pump. This system is called Photovoltaic Thermal system (PVT system) (Joshi and Dhoble, 2018)(Urchueguia, 2016).

- A *geothermal heat pump* uses heat from warm earth layers. There are two different geothermal heat pump systems which are the vertical geothermal heat pump and the horizontal heat pumps. The horizontal geothermal heat pump is a system with vertical pipes in the ground, which can be between 10 and 250 meters in the ground to collect heat from very deep earth layers . A horizontal geothermal heat pump contains horizontal pipes between one and three meter in the ground to collect seasonal temperature differences (Urchueguia, 2016). In both vertical and horizontal geothermal heat pumps, a liquid is heated in a pipe system to heat up water in the water tank. In a geothermal heat pump, electricity is only used to operate the pump to pump a chemical liquid through an underground pipe system and to operate the compressor for heating the water. For Irmão however, this system will be very difficult to implement because of the ban on building in the dunes.

  Similar to the water-water heat pump, the COP value of a geothermal heat pump normally varies between 3.0 and 5.0 (Dincer and Rosen, 2021). This leads to an average COP value of 4.0. Taking into account an efficiency of 400%, an electricity consumption of 6.83 kWh/day is estimated for geothermal heat pump. This leads to a CO_2 emission of 1.65 kg/day which is a reduction of 80% compared with the gas water heater.

In table 13.3, a multi-criteria analysis of the water heater systems is given. The most important criteria are the environmental impact and the cost. The environmental impact relates to the efficiency of the water heater or heat pump and to their impact on the environment in terms of required constructions such as pipe systems. It can be noticed that the water-water system has a relative low weighted total score. This can be related to the difficulty to implement the system at Irmão due to regulations and costs. Geothermal does have a good score but similar to the water-water system, the geothermal system has a high cost and is difficult to implement at Irmão due to dune protection regulations. The all-electrical system and the air-water system have a very high weighted total score but solar thermal does outscore them, because solar thermal has a lower environmental impact. Solar thermal scores the best on environmental impact because it has the highest efficiency compared with the other devices as stated above. Therefore, it can be concluded that the solar thermal system is the most suitable system to implement at Irmão.

13.3. Possible renewable energy sources

The electricity consumed from the local Portuguese electricity grid leads to a CO_2 emission of 0.241 kg/kWh, as mentioned in section 12.1. The emitted CO_2 per kWh electricity can be reduced by consuming electricity generated by a renewable energy source. Therefore, this section will provide an overview of the possible renewable energy sources for Irmão. Renewable energy can be generated in many different ways these days. However, only the most common energy sources will be considered for this study. In this section, the feasibility of solar energy, wind energy, wave and tidal energy, and biomass energy micro generation are examined. These four different main sources are compared with each other through a multi-criteria analysis.

The different sources are assessed on two topic-specific criteria in addition to the 7 standard criteria. These two topic-specific criteria are the total potential of the generating source and the continuity of the source. The total potential indicates how much energy can be generated specifically at the location or

Table 13.3: Multi-criteria analysis of a Gas water heater, All-electrical water heater, Air-Water pump, Water-Water pump, Solar thermal pump and a Geothermal heat pump.

General criteria	Weight	Gas	All-Electrical	Air-Water	Water-Water	Solar thermal	Geothermal
Cost	4	4	5	4	1	3	1
Ease of implementation	3	4	4	4	1	4	1
Maintanance	3	3	4	4	2	4	4
Environmental impact	5	1	2	4	3	5	5
Esthetics	2	3	5	3	4	4	5
Lifetime	2	4	4	4	2	4	4
Topic specific criteria							
Noise level	1	4	4	3	5	5	5
Safety	3	2	4	4	4	4	5
Weighted total		**66**	**88**	**89**	**57**	**94**	**82**

in the vicinity of Irmão. The continuity of the source expresses how constant the supply of energy is from the source in question.

Table 13.4: MCA of the possible energy sources evaluated on multiple criteria.

General criteria	Weight	Wave & tidal	Solar	Wind	Biomass
Cost	5	1	5	4	4
Ease of implementation	3	1	5	4	3
Maintenance	4	5	3	4	4
Environmental impact	5	4	5	5	1
Aesthetics	3	5	5	3	2
Lifetime	4	4	4	4	2
Topic specific criteria					
Potential of generation	5	5	4	3	2
Continuity of generation	4	3	3	5	5
Weighted total		**116**	**140**	**133**	**94**

Solar energy
As mentioned previously, the potential of solar energy in Portugal, and Costa da Caparica in particular, is high. With an estimated solar radiation of more than 1700 kWh/m^2 annually, micro generation by solar cells is promising. The disadvantage of solar energy is that it can only be generated during the day, therefore the continuity is lower. An advantage of solar energy is that installation and maintenance are relatively user-friendly.

Wind energy
Wind speeds on the Costa da Caparica are relatively favourable and fairly constant throughout the year. Also, daytime and nighttime have a relatively small impact on the total amount of wind energy to be generated. Since the intention is not to install a multiple megawatt wind turbine, but a micro generation wind turbine, the potential of the total amount of energy to be generated is relatively lower. Despite the size of the wind turbine, it is not aesthetically the best solution. On the other hand, the installation and maintenance of the wind turbine is relatively easy. Also, the cost of the windmill is relatively low.

Wave and tidal energy
Wave and tidal energy are forms of energy that are derived from the kinetic energy of water. The continuity of these methods of generation are both very high due to the constancy of the tides and currents. The potential of these sources is therefore also relatively high. However, both forms are still in their early stages in terms of micro-generation. Relatively little research has been done compared to, for example, micro-wind and micro-solar power generation. The costs associated with wave and tidal energy installations are therefore still far too high. The installation of a micro tidal generator is relatively complicated. Also, the installations may be harmful to aquatic life.

Biomass

Using biomass as a source of sustainable energy is a concept that has been around for centuries. Biomass contains chemical energy that has been provided by the sun. Biomass can be used as an energy carrier in various ways. Biomass can be burned directly to create heat or converted into a liquid, gas or solid state of fuel.

The debate as to whether the use of biomass is sustainable or not has not yet been settled as the highest achievable result is CO_2-neutrality. This is because burning something can only emit the amount it once stored. So burning biomass is not better for the climate but it is not worse either. On the other hand, the use of biomass could extract energy from goods that would otherwise be thrown away. Aesthetically, burning biomass is a relatively bad choice as it can create smoke and unwanted odours. Also, the potential of burning biomass is relatively low due to its low efficiency. The continuity is determined by when the biomass is burned. This can happen at times when the demand for energy is high, which is therefore advantageous.

As can be seen in table 13.4, after valuing the different criteria and multiplying the weighting, the solar and wind installation are the most advantageous and would therefore be possible energy sources. But, after consultation with the beach restaurant owners, it was decided not to opt for wind energy due to aesthetic considerations. Also, given the fact that the dune area is protected, it is expected that the permits for placing the wind turbines would be very difficult. For this reason, only solar energy is taken into account for the rest of this study as possible energy sources. The precise potential of these sources is discussed in chapter 14.

13.4. Summary energy system solutions

The goal of this chapter is to compare different possibilities to improve the sustainability of the energy system of Irmão. This is done by investigating the possibility to decrease the energy consumption in section 13.1, the switch from gas to electricity in section 13.2 and to compare the possibility to generate renewable electricity.

First in section 13.1, it becomes clear that decreasing the energy consumption of Irmão by purchasing new devices with high efficiencies would not lead to significant progress in sustainability because Irmão already uses devices with relatively good efficiencies. Besides, it becomes clear that the positioning of specific electrical devices could lead to a decrease in energy consumption but Irmão has taken that into account.

Secondly, in section 13.2, the switch from gas to electricity is discussed. Alternatives are presented for the currently used gas devices. After comparing the alternatives, the most suitable option is selected per gas device. For the gas cook stove it is clear that the induction cook stove is the most suitable option. For the deep fryer, the electrical deep fryer suited the most because an induction 2x20 liter deep fryer is not available. Concerning the gas water heater, it becomes clear that a water-water heat pump is the best option in combination with a PVT system. A detailed specification of the selected alternatives for the gas devices will be given in section 14.1.

Finally, in section 13.3, different renewable energy sources are reviewed. It is clear that solar energy is the most suitable option to implement at Irmão. Renewable energy generation with wind turbines, wave and tidal or biomass is proven to be to expensive or enormous installations must be build to meet the energy demand of Irmão. Solar energy will be converted to electricity with PV panels. The PV panels can be placed on the roof of Irmão and above the walking path from the parking place to the restaurant. The detailed design of the PV system will be given in section 14.2, section 14.3, section 14.4 and section 14.5.

14

Energy system solutions worked out

After analysing the current energy infrastructure of Irmão in chapter 12 and providing the possible solutions in chapter 13, this chapter will provide the worked out solutions of the energy system. The worked out solutions of the energy system are given to have an insight in the replacement of gas devices and a full understanding of the PV systems. The chapter focuses on two different components of the energy supply, namely gas and electricity. First, in section 14.1, the replacement of gas devices will be elaborated. Hereafter, in section 14.2, background information about solar panel installations and all aspects required to install the most promising solar energy system are given. Furthermore, in section 14.4 and section 14.5, a detailed explanation of the solar energy system on the roof and walking path is provided. Hereafter, the Balance of System is explained in section 14.6. Finally, section 14.7 will provide a summary on the worked out energy solutions.

14.1. Gas to electricity final solutions

The possible options for replacing the gas with electrical devices are described in section 13.2. It became clear that switching from gas to electricity reduces the CO_2 emissions and is therefore considered to be more sustainable. In addition, when electricity is generated with PV panels as explained in section 13.3, the emissions and cost of the electricity consumed by the new electrical devices can be significantly reduced. In this section the final chosen solutions will be further presented. Section 13.2 concludes that best results can be expected if the gas cook stove is replaced by the induction stove, the gas deep fryers are replaced by electrical deep fryers and finally if the gas water heater is replace by the PVT system. This system will be explained in detail in this section.

14.1.1. Induction cook stove

To replace the current used six-hob gas cook stove, a combination of two induction cook stoves is selected. In figure 14.1, two induction cook stoves from the same company called *GGM Gastro* are shown. The cook stove on the left contains four hobs and the induction cook stove on the right contains two hobs. Two separated induction cook stoves were preferred by the owners of Irmão due to the extra space around the stoves. Therefore, a combination of two induction cook stoves will be used.

The induction cook stoves combined have six times 3 kW hobs resulting in a total of 18 kW. This is sufficient since this is above the required 12 kW effective power calculated in section 14.1.1. Meaning that the induction cook stoves do not have to operate at maximum power when assuming the same required power as of the gas cook stove. The induction cook stoves combined will have to operate at the same effective power as the currently used gas cook stove. This leads to a daily energy consumption of 18.2 kWh as explained in section 13.2.1. Taking into account the amount of days Irmão uses the cook stove, an annual electricity consumption of 4,876 kWh is calculated. Besides, the maximum electrical power requirement of Irmão increases with 18 kW. Regarding the induction cook stove, the emission of CO_2 will be reduced with 53% to 1.17 ton per year when electricity from the grid is used instead of gas.

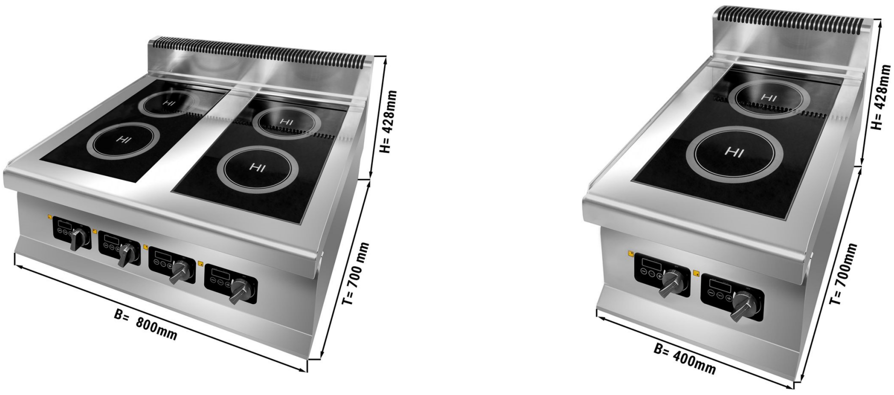


Figure 14.1: Four-hob induction cook stove (left) and two-hob induction cook stove (right).

The cost of both induction cook stoves combined is €2.333,- (excl. Vat). The cost of gas used for the gas cook stove is estimated to be €1.373,- annually. The cost of electricity from the local electricity grid is estimated to be €784.- per year. This is a decrease of 43% in energy cost for the cook stove.

14.1.2. Electrical deep fryers

To replace the current used gas deep fryers, the electrical deep fryer shown in figure 14.2 is selected. This is a Magnus 2x20 Liter electrical deep fryer and has the same fryer capacity as the currently used gas deep fryers. This electrical deep fryer has a two times 12 kW deep fryer. With an efficiency of 80%, this leads to a combined effective power of 19.2 kW which is higher than the effective power of the current used gas deep fryer.

The electrical deep fryers must operate at least at the same effective power as the gas deep fryers to maintain the required power. This leads to a daily energy consumption of 24.43 kWh as explained in section 13.2.2. Taking into account the amount days Irmão uses the deep fryers, an annual electricity consumption of 7110 kWh is calculated. Besides, the electrical power requirement of Irmão is increased with 24 kW. Regarding the electrical deep fryers, the emission of CO_2 will be reduced with 33% to 1.71 ton per year when electricity from the grid is used instead of gas.

The cost of the Magnus deep fryer is €1.562,- (excl Vat). The cost of gas used for the gas cook stove is estimated to be €1.424,- annually. The cost of electricity from the local electricity grid is estimated to be €1.143,- per year. This is a decrease of 20% in energy cost for the deep fryers.

Figure 14.2: Electric deep fryers Magnus 2x20L.

14.1.3. PVT water heating system

The gas water heater will be replaced by a solar thermal water heat pump system as explained in section 13.2.3. Because of the lack of space at Irmão, a photovoltaic thermal (PVT) system is chosen. A PVT system combines the generation of electricity with the thermal heating of water. In figure 14.3, a PVT system configuration is provided. The PVT system consist of four devices which can be seen in figure 14.4 and a cabling network. The first device is the PVT solar panel depicted with I. The second device is the boiler tank depicted with II. The third device is the heat pump indicated with III. The fourth device is the Power inverter denoted with IV.

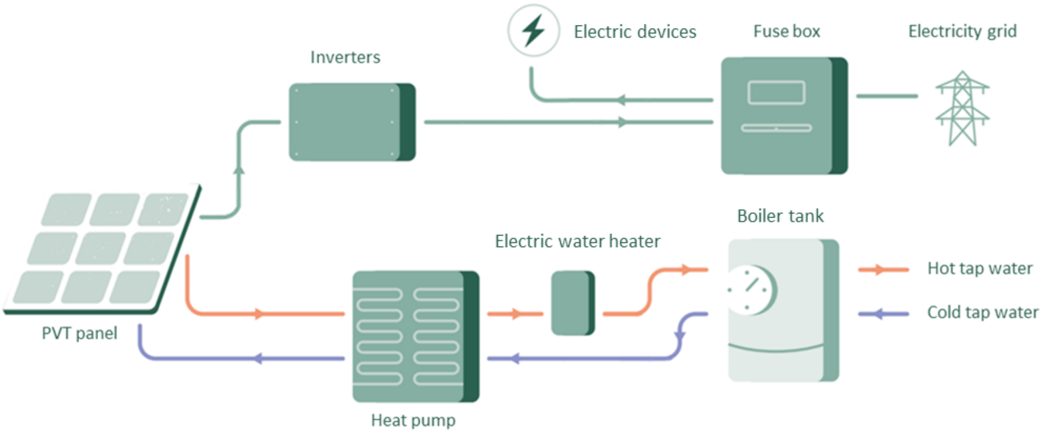


Figure 14.3: Total PVT system configuration.

Figure 14.4: PVT system: I. PVT panel, II. Boiler tank, III. heat pump, IV. Power inverter.

In this system, a liquid mixture of water and glycol flows through pipes under the photovoltaic panels, where it is heated by the sun. This heated fluid then flows to the heat pump, that it is used to warm up tap water. This is called a closed loop system (Canbaz et al., 2021). Because the fluid mixture does not always contain enough heat energy to adequately heat the tap water, additional heating can take place in the electric water heater before it flows into the boiler where it is being stored. The electricity generated in the PVT panels is inverted and ready to use for electricity devices at Irmão. The electricity part will further be discussed in section 14.2.

To replace the gas water heater at Irmão, a PVT system with the following specifications is required. In consultation with Volthera, which is a company specialized in PVT systems, is predicted that the PVT system of Irmão must consist of the following specifications. The PVT system must consist of eight PVT panels, a 6 kW heat pump and a boiler tank of 200 Liter is required. This system will provide enough warm water as is required in the current situation. To calculate the electricity consumption of the electric heat pump, a COP value of 3.0 is used. This COP value is used to simplify the calculation because a full simulation of the PVT system for a full year proves to be very time-consuming and lies therefore beyond our scope. The estimated daily energy consumption of the PVT system is 9.06 kWh which is calculated with a COP of 3.0 and the current energy consumption of the gas water heater. This is a reduction of 75% compared with the energy consumption of the gas water heater. Regarding the PVT system, the emission of CO_2 will be reduced with 73% to 0.59 ton per year when electricity from the grid is used instead of gas.

The cost of the total PVT system is estimated to be around €15.000,- according to Volthera. The largest expense of the system is the heat pump with an estimated purchase price of €8.000,-. However, using the PVT system, no gas is required to heat up water and therefore €1134,- will be saved annually. The electricity cost for the PVT system are estimated to be €392,- when electricity from the local electricity grid is used. However, the PVT system does also generate electricity with the PV part of the PVT system. When the electricity from the PV panels is used, no additional electricity is required from the grid.

14.2. Solar energy system background

For the optimal installation of the solar module construction, different configurations must be set up and weighed against each other. All necessary aspects for determining these configurations are discussed in this section.

14.2.1. Required data

To set up these configurations, data is needed that was provided in previous chapters. The data used for setting up these configurations are as follows. From chapter 4, data relevant to the climate is extracted. It concerns the parameters: irradiation, sun height, cloud cover and wind speed. From chapter 3, data relevant to the available space to place the structure is taken. The relevant data concern the available roof area, the slope of the different roof sections, the general orientation, the sky view factor (SVF), and the albedo

14.2.2. Components of irradiance

The total irradiance collected on a solar panel, indicated by G_{module} can be divided into three different components. The exact calculation of the components is elaborated on in Appendix A.4.

Direct component. The first component is called the direct irradiance and is indicated by Gm_{Dir}. As mentioned previously, the AOI plays large part in the direct irradiance experienced by the panel.

Diffuse component. The second component is the diffusive radiation and indicated by Gm_{Dif}. This is the radiation that reaches the panels after being scattered from the direct solar rays by interaction in the atmosphere.

Albedo component. The third component is called the albedo component and is indicated by Gm_{Alb}. The albedo component is the irradiance that reaches the panel after being reflected by surrounding surfaces.

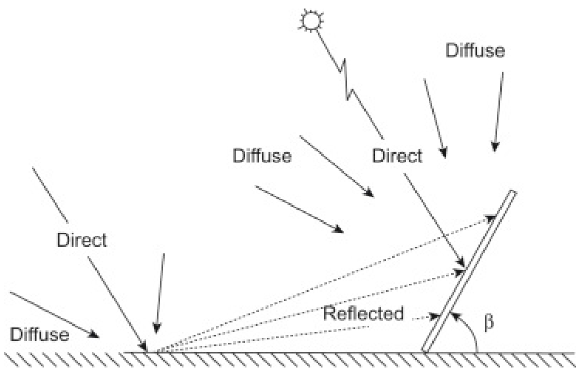


Figure 14.5: Schematic representation of the 3 components (Reca-Cardeña and López-Luque, 2018).

14.2.3. Site conditions

Since the solar panels will be installed close to the ocean, it is important that the panels are resistant to the possible effects of the presence of salt. This is because corrosion can occur in the solar cells, the steel can galvanise and sea grime can occur. For this reason, there are standards that the solar panels must meet: the IEC61701 standards. There are various gradations within this standard, ranging from level 1 to 6, with 6 being the most resistant to salt corrosion. As the life span of the solar panel is 25 years, the highest level of salt corrosion resistance must be met.

14.2.4. Panel choice

In order to calculate the amount of energy that can be generated and compare different configurations, it is necessary to select a specific PV panel and perform the calculations. When choosing the panel, two requirements are taken into account. These are that the panel must comply with the aforementioned IEC 61701 standard and that the panel must be available in the Lisbon area. Next, the panels found are compared on the basis of efficiency, power temperature gradient and cost. The power temperature gradient is the increase or decrease of power due to the temperature of the panel. When the temperature of the panel rises, the power it can deliver decreases. However, when the panels are colder than the reference temperature, the power increases. The temperature to be compared is called the Nominal Operating Cell Temperature (NOCT).

Based on the set criteria, four different panels were found from three different brands. The brands found are: LG, Sunpower and REC. The four different panels are presented in table 14.2.4.

Table 14.1: Different PV panels and their characteristics.

Brand	LG	LG	Sunpower	REC
Type	395N2T	370Q1C	Maxeon 3	TwinPeak 2
Efficiency [%]	18.7	21.4	22.1	17.0
Dimensions [mm x mm]	1675 x 997	1016 x 1700	1046 x 1690	997 x 1675
Costs per panel [€]	345	278	376	167
NOCT [°C]	45.0 ±3	44.3 ±3	44.0 ±1	44.6 ±2
Power Temp. gradient [%/°C]	-0.36	-0.30	-0.27	-0.37
Reference	(LG, 2020)	(LG, 2021)	(Sunpower, 2020)	(REC, 2021)

Of all the panels, the TwinPeak panel from REC has a significantly lower price than the other three panels, but this is also accompanied by the lowest efficiency. Also, the performance of the panel decreases the most with respect to temperature. A factor that is not advantageous in the relatively warm Portugal. The Maxeon 3 panel from the Sunpower brand has the highest efficiency but again this is reflected in the price. The power temperature gradient is also favourable. The 395N2T panel from LG has a low output for its relatively high price and the power temperature gradient is also unfavourable.

The 370Q1C panel from the brand LG combines both favourable price and performance. It scores high in terms of efficiency and also has a favourable power temperature gradient. The price paid for these panels is significantly lower than that of the Sunpower Maxeon 3 panels, which score about the same in terms of performance. Because of the above reasoning, it is chosen to use the 370Q1C panel of the LG brand. The specifications can be found in appendix A.2.

14.2.5. Panel orientation

Solar panels can be installed in two different orientations. If they are installed with their long side parallel to the roof ridge, this is referred to as landscape mode. When the panel is installed with their short side parallel to the roof ridge, this is referred to as portrait mode. Figure 14.6 depicts the differences between portrait and landscape orientation.

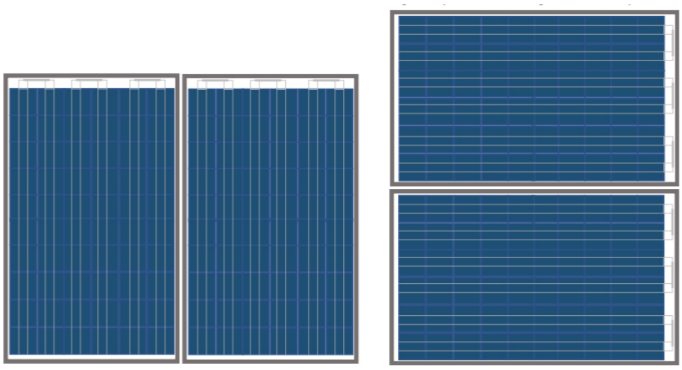


Figure 14.6: PV panels in landscape and portrait mode Island, 2021.

14.2.6. Tilt and azimuth

The angle of the solar panel in relation to the sun is called the angle of incidence (AOI). The smaller the AOI, the more straight the sun shines on the panel. As a result, the panel can generate more electricity. It is therefore important to position the panels at the right angle. The AOI consists of two separate angles, a vertical angle and a horizontal angle. The vertical angle is the angle the panel makes with the flat surface and is called the tilt angle. The horizontal angle, known as the azimuth, is the angle that the panel makes with the equator. Figure 14.7 gives a representation of the azimuth and tilt angle. The optimum angle changes from minute to minute throughout the year as the sun rises in the east and sets in the west and as the seasons influence the height of the sun, the so-called solar height. By combining the solar height, solar rotation, and module irradiance together, the graph in figure 14.8 was created.

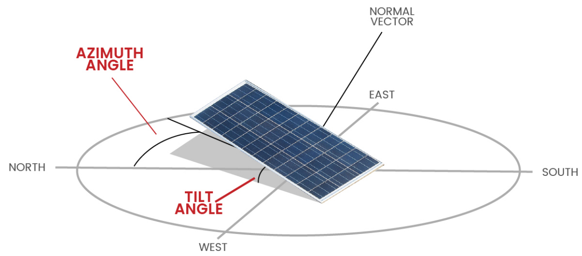


Figure 14.7: Azimuth angle and tilt angle (Electrical, 2019)

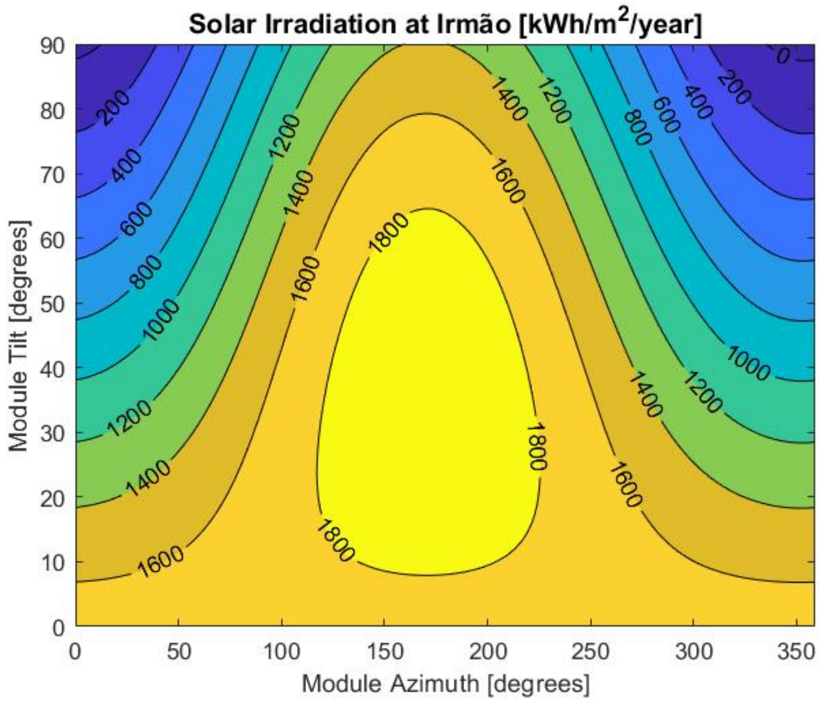


Figure 14.8: Irradiance per tilt and azimuth angle at Irmão. Graph created with Matlab

The figure shows what the annual solar irradiation would be on a panel if this panel is installed at a specified tilt angle and azimuth angle. It shows that the optimal angle is a tilt angle of 37 degrees and the azimuth angle is 172 degrees. The annual irradiation received amounts to 1957 kWh/m^2. However, the seaside roof has a tilt angle of 13 degrees and an azimuth of 240 degrees. The backside roof has a tilt angle of 13 degrees and an azimuth of 80 degrees. The seaside- and backside roof receive and annual irradiance of 1740 kWh/m^2 and 1671 kWh/m^2, respectively.

14.2.7. Power temperature gradient

As mentioned earlier, the efficiency of solar panels is influenced by the temperature of the module. When the module temperature rises above the Nominal Operating Cell Temperature (NOCT), the efficiency decreases,and visa versa. When the module temperature is below NOCT, the efficiency increases. The temperature of the model depends on a number of different factors. These factors are the air temperature, the module temperature at the previous hour, the absorption coefficient, and the module emissivity. With this data, an iteration is performed that calculates the temperature of the module for a given hour. This module temperature is then compared to the NOCT. The difference, negative or positive, is then used to calculate the difference in delivered power. Figure 14.9 presents the temperature of the panels during the year.

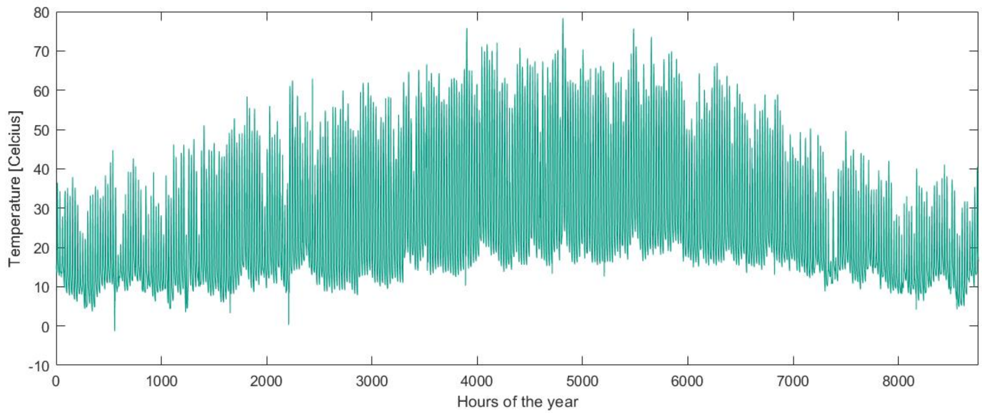


Figure 14.9: Temperature of the PV panels during the year

Due to the dark surface of the panels, large quantities of sunlight are absorbed, as desired in a solar panel. This also causes the panel temperature to rise significantly, especially during the summer months. The panel surface temperature can reach temperatures as high as 78 degrees Celsius. To give an impression, the mean temperature of the panels is 26.13 degrees Celsius in the summer months. The PV panel temperature will be used to calculate temperature dependent power output of the PV system.

14.3. PV system type

The solar panel systems on roof and the over the walking path are both grid tied systems. The schematic overview of a grid tied system is given in figure 14.10. A grid tied system means that the generated electricity is first sent to the inverter and the fuse box where will be determined if there is an oversupply or under supply of electricity. When there is an oversupply of generated electricity, the excess of electricity is sent to the local electricity grid. When the generated electricity is not enough to cover the electricity demand of Irmão, the electricity demand of Irmão is supplemented by the local electricity grid. In this way the electricity is ”stored” in the local electricity grid. Therefore, it is possible to cover the annual electricity demand with the annual electricity generation of the solar panels. A grid tied system is selected because this type of system does not require any battery systems. Not using an extra battery system is preferable because most batteries contain heavy metals which can pollute to the environment (Melchor-Martínez et al., 2021). Besides, not using batteries reduces the solar energy system cost significantly. The second reason a Grid tied system is selected relates to the lack of specific hourly electricity consumption data. Due to the lack of specific hourly electricity consumption data, it is impossible to determine the exact amount of energy storage needed to cover the electricity demand with the solar electricity generation. A grid tied system is selected because it does not require an extra energy storage installation. Important to mention is that a grid tied system must be installed in

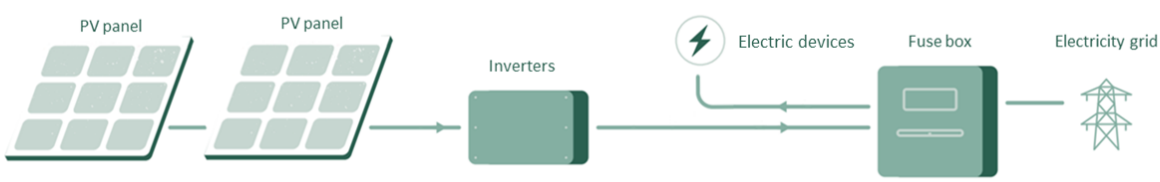


Figure 14.10: Electricity infrastructure Irmão.

consultation with the local electricity grid company. The reason for this is that grid frequency problems can occur if a significant amount of electricity is added to the grid. The grid tied systems of the roof and over the path both consist of an inverter, cables and the solar panels which can be seen in figure 14.10. The Fuse box will be used to measure the power generated by the solar panel installation and is not part of the PV solar system.

14.4. Solar roof

To find the most promising PV panel lay-out, multiple configurations are examined and discussed in this section. In order to compare the configurations, it is first examined how much energy a single panel can generate in the respective orientation. When calculating the energy to be generated, only the panel efficiency is taken into account for now. This means that the temperature-dependent efficiency and the losses through cables, maximum power point tracker and inverter are not yet taken into account. After this, the amount of energy that the entire roof could generate is considered. It is important to consider the entire roof, as the orientation of the panel affects the total number of panels to be installed.

14.4.1. Base configuration

The first configuration that will be examined is called the *Base configuration*. In this configuration, the solar panels are positioned in the same orientation of the roof. This implies that the panels have the same tilt and azimuth angle as the roof.

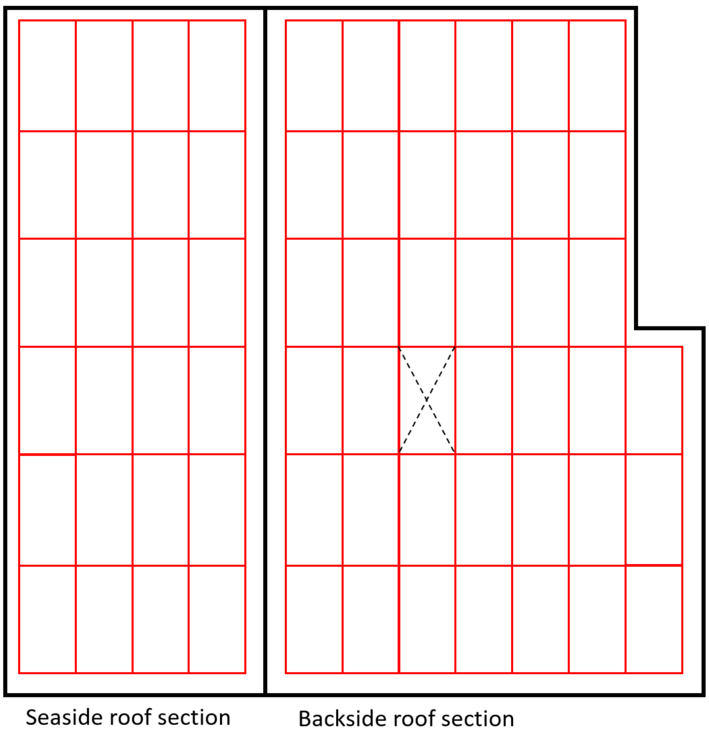


Figure 14.11: Schematic representation of the top view of the *Baseline configuration*

Seaside The location of the panels at the seaside of the roof are relatively more advantageous than those at the backside of the roof. This is due to the slight inclination towards the south. Following the orientation of the roof, this means that the panels are installed with a tilt of 13 degrees and an azimuth of 240 degrees. During one year, it is calculated that a single panel on the seaside roof section in the *Base configuration* can generate 642.6 kWh. Taking into account the dimensions of the chosen panel, a maximum of 24 panels fit on the seaside roof, this is when the panels are installed in landscape orientation. The panels are installed in 4 rows and 6 columns. The total energy that can generated by this roof section comes down to 15.4 MWh per year.

Backside The backside roof area will yield slightly less than the seaside roof in the *Base configuration*.

The panels on this roof section lie under a tilt of minus 13 degrees and an azimuth of 240 degrees. The total energy that a single panel will generate annually is 617.6 kWh. The backside roof consists of two separate sections with the same orientation. On the one roof section, 7 rows of 3 columns fit. In this section, one panel must be removed because there is a chimney. Six rows of three columns fit on the second section, making a total of 18 panels. The total of the backside roof section is 38 panels. The total energy that the backside roof section can generate annually is 23.5 MWh. Combining both the seaside roof and backside roof of the *Base configuration* results in an annual generation of 38.9 MWh.

14.4.2. Tilted configuration

The second configuration, the *Tilted configuration*, does maintain the same azimuth as the roof (240 degrees), but sets the panels at the optimal tilt angle for that azimuth (17 degrees). Although, as shown in the figure 14.8, this captures more solar radiation when a single panel is installed, it can have adverse effects when multiple rows of panels are installed. This is because the increased tilt angle results in shadow being created behind the panel in question. This is visualized in figure 14.13. In this figure, shadow created by an irradiance coming from a Sunheight of 60 degrees is shown in gray. This Sunheight is representative for hours during the summer when the sun is at its highest point. During the hours that the sun is at a lower angle, the shadow is even larger. A solution to this problem would be to place the panels further apart. This would ensure that they receive the same amount of irradiation as the front row of panels, although fewer rows of panels would then fit on the roof.

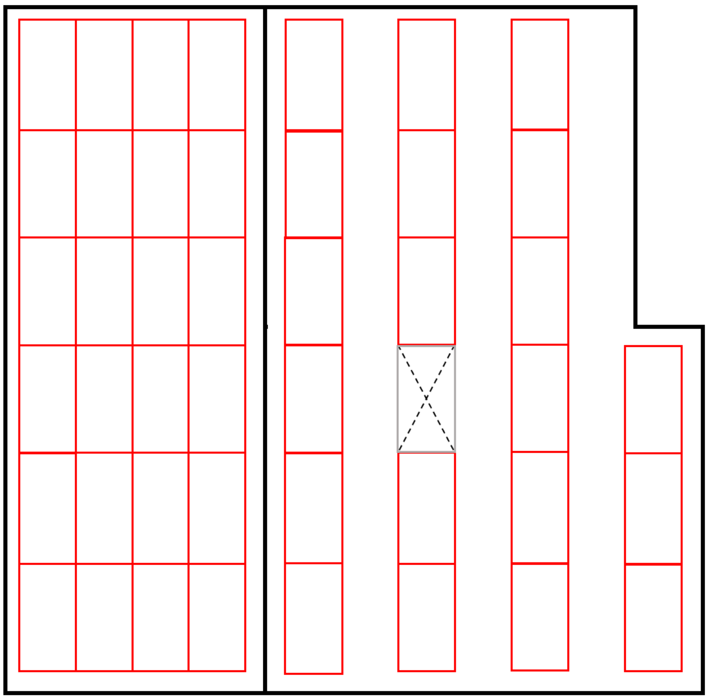


Figure 14.12: Schematic top view representation of the *Tilted configuration*

Seaside As mentioned, in this configuration, the azimuth of the panels remains the same as that of the roof. At this azimuth of 240 degrees, the ideal tilt angle is 17 degrees. This is 4 degrees in addition to the angle that the roof already makes on the seaside rooftop. As figure 14.13 presents, there is only a small shadow zone created by this additional tilt. Therefore it is assumed that this effect can be neglected and that the same configuration as in the *Base configuration* can be used, namely a total of 4 rows and 6 columns. It is calculation that 1 panel can generate 642.9 kWh/year leading to a total generation of 15.4 kWh annually.

backside Because the panels on the backside are in the same orientation as the panels on the seaside, a single panel on either roof section will generate the same amount of energy annually, being 642.9

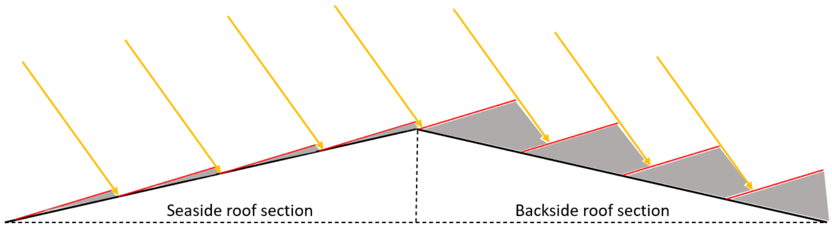


Figure 14.13: Schematic representation of the tilted panels on the seaside and backside roof section with irradiance coming from the sun at a Sun height of 60 degrees

kWh. Nevertheless, on the backside roof section, the consequences of installing the panels under the perfect tilt are larger. As the backside roof orientation is at a tilt of minus 13 degrees, increasing the tilt of the panels to the ideal tilt (17 degrees) results in a increment of 30 degrees. This results in the creation of a large shadow being cast behind the panels of the first row, as seen in figure 14.13.

To make up for the shadow created by the inclination, the panels are placed further apart as seen in figure 14.12. Per panel at the backside roof section, the annual generation is 621.7 kWh. The total backside roof section would generate 12.4 MWh then annually. Combining both the seaside and backside, the *Tilted configuration* generates 27.9 MWh annually.

14.4.3. Optimal angle configuration

The third configuration, *Optimal angle configuration*, places the panels at the ideal tilt angle and the ideal azimuth angle. This has the disadvantage, besides the previously mentioned disadvantages of the *Tilted configuration*, that the square panels fit less well on the square roof than in the base or *Tilted configuration*. Also, extra space between the panels must be added to make up for the shadow created behind the tilted panels. The panels are placed in the figuration presented in figure 14.14.

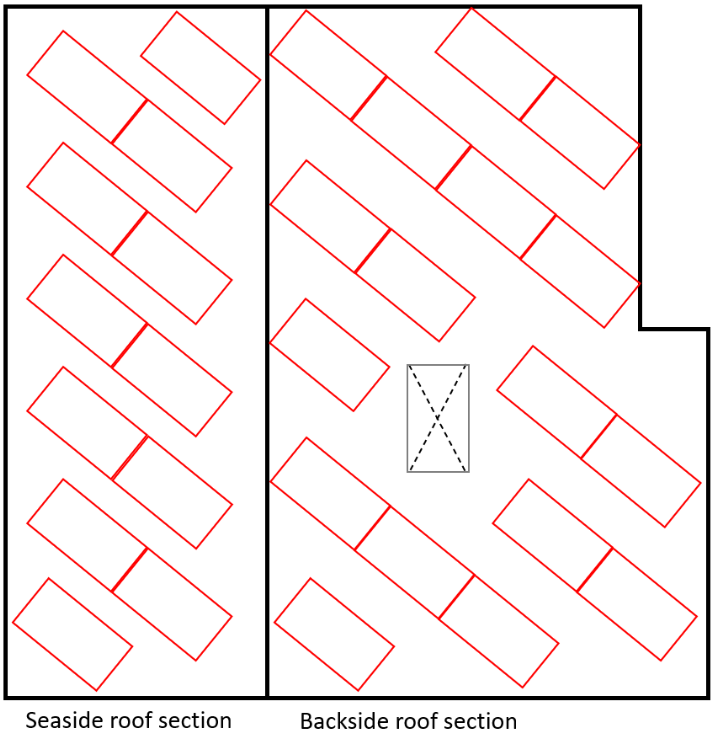


Figure 14.14: Schematic top view representation of the ideal tilt configuration

Seaside Placing the panels under the ideal tilt and azimuth means that the panels are placed at a tilt of 36 degrees and at a azimuth of 172 degrees. As the orientation of the roof is 240 degrees, the panels are rotated 68 degrees counter clockwise, towards the south. A single panel in this configuration generates 720.8 kWh annually. Due to the rotation in azimuth, the panels doe not fit well on the roof sections. Therefore, only a total of 12 panels can be installed on the seaside roof section. The total seaside roof section will generate 8.7 MWh annually.

Backside The same difficulties that the backside roof section of the *Tilted configuration* are experienced at the backside roof section of the *Optimal angle configuration*. The panels are placed at a tilt of 36 degrees which implies that the angle of the panels is increased by 49 degrees compared to the roof orientation. The panels are therefore placed even further apart than at the *Tilted configuration*. The total amount of panels that can be installed is 17. The annual generation is 720.8 kWh which means that the total generation of the backside roof section is 11.9 MWh annually. The combined annual generation of the two rooftops is 20.9 MWh.

14.4.4. Conclusion on roof top PV panel configuration

All three different configurations have their advantages and disadvantages. Table 14.4.4 shows the generation per configuration per roof section for a single panel and the entire roof section.

Table 14.2: Comparison of the different solar panel configurations.

Configuration	Base		Tilted		Optimal angle	
Section	Seaside	Backside	Seaside	Backside	Seaside	Backside
Single panel	642.6 kWh	617.6 kWh	642.9 kWh	621.7 kWh	720.8 kWh	701.4 kWh
Placeble panels	24	38	24	20	12	17
Section generation	15.4 MWh	23.6 MWh	15.5 MWh	12.4 MWh	8.7 MWh	11.9 MWh
Total generation	38.9 MWh		27.9 MWh		20.6 MWh	

The *Base configuration* has the lowest yield per panel compared to the other two configurations, but because the orientation allows for a significantly larger total number of panels to be placed, this results in the highest total amount of energy being generated. Another advantage of the *Base configuration* is that the construction in which the panels are placed, is relatively the simplest.

The increase of the tilt angle in the *Tilted configuration* has relatively little effect on the seaside roof section compared to the *Base configuration*. Per panel it yields 0.1 kWh more annually. Nevertheless, a single panel on the backside produces significantly more electricity than in the *Base configuration*. However, due to the increase in tilt angle, the shadow length is increased to such an extent that it has a negative influence on the number of panels that can be placed on the backside roof section. Therefore the total amount of energy to be generated is lower than in the *Base configuration*. The construction is also more complex than the *Base configuration*.

Finally, the *Optimal angle configuration* produces by far the most electricity per panel than the other configurations, due to the adjustment in both tilt and azimuth. However, these changes do have a large influence on the total amount of panels to be installed on both the seaside roof section and the backside roof section. The total amount of panels that can be installed is decreased to such an extent that the total amount of energy to be generated is the lowest of all three configurations. Also the construction of the panels is the most complex.

Both the *Base configuration* and the *Optimal angle configuration* can be the most advantageous, depending on the purpose of the PV panel roof installation. The *Base configuration* generates the most energy in absolute terms. This is because significantly more panels can be installed compared to the reduction in yield per panel due to non-optimal placement. The *Base configuration* is therefore the most advantageous from a total energy generation point of view.

The *Optimal angle configuration* generates significantly more energy per panel. This ensures that the installation generates the most energy relative to the installation costs, given that the panels are the largest cost source of the entire installation. The *Optimal angle configuration* is therefore the most advantageous from a financial point of view. Since it is more important for the purpose of this study, to generate as much sustainable energy as possible, the *Base configuration* has been preferred and implemented in the integrated design.

14.5. Solar path

The generation of electricity with the solar panels on the roof or Irmão has proven to be not sufficient to meet the annual electricity demand of Irmão, as only around 40 % can be generated by the rooftop system. Therefore, additional solar panels can be installed to above the currently existing walking path from the parking place to the restaurant as explained in section 3. Placing the panels at this location brings several advantages. Firstly, because the path is long, there is a lot of space available to place panels. Secondly, visitors to Irmão are protected from the sun because they walk in the shade below the panels. Finally, the installation is placed adjacent to Irmão, which means that it is clear that the installation is part of Irmão. This will highlight the efforts made by Irmão to become sustainable to the customers.

Figure 14.15 (a) provides a top view visualisation of what the solar path will look like. As can be seen, it consists of three rows of solar panels stacked on top of each other. A single column of three rows will be called a "solar path unit". In figure 14.15 (b), a schematic design of the solar path can be seen. The total required number of solar path units depends on the total amount of energy that is expected to be consumed by the restaurant in the future. This will be further elaborated in chapter 16.

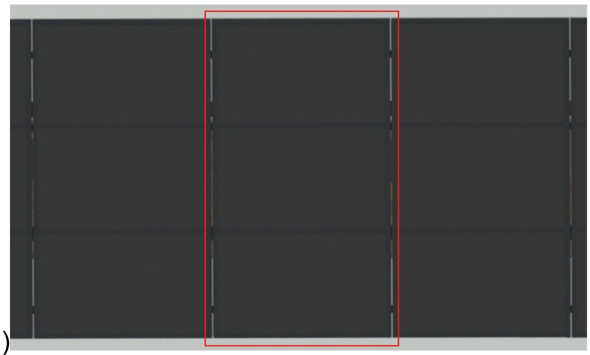
(a)  (b) 

Figure 14.15: (a) Top view of the solar path with in red indicated a single solar path unit. (b) Front view of the solar path seen from the restaurant, made in Revit.

As indicated in chapter 3, the solar path consists of three different sections which have an azimuth of 215, 208, and 226. The ideal tilt angles associated with these azimuth angles are 29, 31, and 25 respectively. Under the above mentioned orientation, the panels receive 1.84 MWh/m^2, 1.87 MWh/m^2 and 1.80 MWh/m^2.

However, placing the panels at these angles means that the installation will be relatively high. Because the panels used are 1 metre wide, and three are placed on top of each other, the panels have a width of 3 metres. If these panels are then placed at an angle of 31 degrees, for example, this means that the panels will rise 1.55 metres into the air. This 1.55 metres is on top of the height of the wooden construction on which the panels stand. A solution to this problem is to place the panels at a smaller angle. When the panels are placed at an angle of 10 degrees, for example, the panels only rise 0.52 metres into the air. When the panels are installed at an angle of 10 degrees, the three different solar path

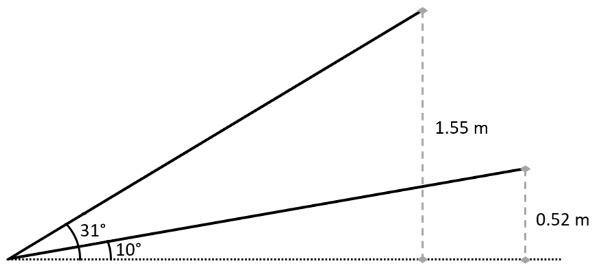


Figure 14.16: Schematic representation of the difference in height of the solar path dependent on the tilt angles of the solar panels.

sections receive an irradiance of 1.81 MWh/m^2, 1.83 MWh/m^2, and 1.78 MWh/m^2 annually, respectively. The difference in angles and its consequences is schematically represented in figure 14.16. As shown in figure 14.16, the horizontal plane under the panels is also shorter. A solar path unit therefore generates 2.00 MWh, 2.03 MWh, and 1.98 MWh annually.

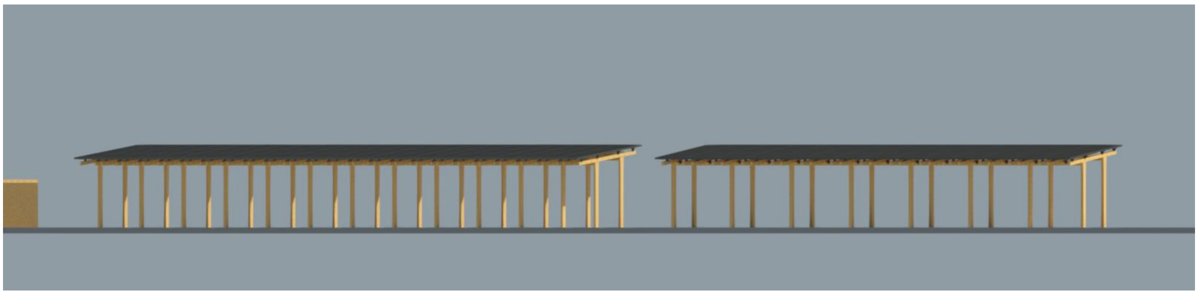


Figure 14.17: Side view of the solar path, made in Revit

Because the difference in annual irradiance is relatively small between installing the panels at their ideal tilt angle versus an tilt angle of 10 degrees, it is decided to place the installation at an angle of 10 degrees. The fact that the installation is less high also means that fewer materials need to be used. This is financially attractive and outweighs the reduced generation.

14.6. Balance of System

The *Balance of system* (BOS) of a solar panel system are all the additional components that are needed to let the system work. In this design with a grid tied system, the components of the BOS are the inverter, the cables and the mounting system.

14.6.1. Inverter selection

The inverter required for the grid tied system is an AC-DC converter to convert the direct current (DC) from the PV panels to alternating current (AC) of the grid. Besides, the inverter must contain a maximum power point tracking (MPPT) mechanism. The MPPT mechanism determines the most efficient output current to reach the highest power output of the solar panel system (Verma et al., 2016). Suitable inverters are the Fronius Symo inverters. The Fronius Symo inverters have two build in MPPT mechanism and therefore two different strings of solar panels can be connected. The reason that the solar panels can not be connected all together to one inverter is that the solar panels are located over a relatively large distance. When several solar panels are shaded by clouds and the irradiance decreases, the total output power will drop significantly because of the MPPT mechanism. A solar panel string is more likely to be affected by different radiation levels when the distance between the solar panels is greater. Therefore, the amount of solar panels connected in one string is limited in order to not reduce to total electricity yield.

The Fronius Symo inverters are available in different maximum output power as can be seen in figure C.4 of Appendix C. The Fronius Symo inverter is available in the maximum output power range of 5-20 kW. The required inverter depends on the maximum input current (I_{DCmax}), the maximum input power (P_{DCmax}) and the maximum output power. I_{DCmax} and P_{DCmax} are determined by the number of panels connected in series or parallel. The I_{DCmax}, P_{DCmax} and maximum output current of the inverter must be higher than the values of the solar panel system. The Fronius Symo inverters have the same efficiency of 98%. The cost of the Fronius Symo inverters is in range of €1.167,- to €2,359.-. The specific selection of the inverters for the different PV solar panel sections will be given in chapter 15.

14.6.2. Cable selection

The cable selected for the PV systems is the KBE 6 mm^2 cable. This cable has a diameter of 6 mm^2 and will be used for the AC and DC parts of the system. The DC part of the PV system is between the solar panels and the inverters. The AC part is between the inverters and the local electricity grid. The KBE 6 mm^2 is selected because it can be used for the DC and AC parts. Besides, the cable has a maximum conductor temperature of 120°, which is preferable for PV systems located in area's with relatively high temperatures such as Costa da Caparica. The cost of the cable is €528,- per 500 meter.

14.6.3. Mounting system

The roof or Irmão is a corrugated iron roof and therefore not all mounting systems can be used. The Schletter mounting system is specifically designed for corrugated iron roofs and is therefore selected for the roof of Irmão. The Schletter mounting system can also be used for the solar path what will reduce the cost because only one system can be used for both PV solar systems. The cost of the mounting system is estimated to be €40,- per solar panel.

14.7. Summary energy system solutions

The solutions to make the energy system of Irmão more sustainable are provided in this chapter. This section provides a brief summary of the detailed solutions that. In section 14.1 the effects on the maximum power, electricity consumption, emissions and cost of implementing three alternatives for gas devices are worked out. Table 14.3 and table 14.4, present the expected results of these calculations. In table 14.4, the initial cost, the new electricity cost and the annual savings per device are given. The annual cost saving is calculated by subtracting the new electricity consumption cost from the currently used gas consumption cost.

Table 14.3: Energy overview electrical alternatives for the gas devices of Irmão.

Device	Maximum power (kW)	Electricity consumption (kWh/year)	Emission reduction
Induction cook stove	18.0	4.880	-52%
Electric deep fryers	24.0	7.110	-33%
PVT system	6.0	2.440	-73%
Total	48.0	14.420	-52%

Table 14.4: Cost overview electrical alternatives for the gas devices of Irmão.

Device	Initial cost (€)	Electricity cost (€/year)	Annual saving (€)
Induction cook stove	€ 2.330	€ 780	€ 590
Electric deep fryers	€ 1.560	€ 1.140	€ 280
PVT system	€ 15.000	€ 390	€ 830
Total	€ 18.890	€ 2.310	€ 1.700

In section 14.2, the background information of the solar energy system is given. Here, the different components of irradiance, specific site conditions, the tilt and azimuth, the solar panel choice and the power temperature gradient are explained. This information is required to understand section 14.4 and section 14.5 where two different solar panel installations are discussed, the one on the roof and one on the path towards Irmão. The selected solar panel is the LG 370Q1C solar panel, which has the necessary IEC61701 standard.

In section 14.4, the solar panel installation on the roof of Irmão is elaborated. The most suitable configuration of the solar panels is the *Base configuration* because the roof has a relatively good tilt angle and azimuth. Besides, the *Base configuration* does not lead to extra shaded spots on solar panels caused by other solar panels. Therefore, the *Base configuration* is the most efficient configuration on the roof or Irmão. The front and backside combined consist of 68 solar panels. The total electricity generation of the solar panel system on the roof is 38.9 MWh per year which is less than 50% of the current annual electricity demand of Irmão. The annual emission of CO_2 caused by electricity consumption will be reduced with 7.1 ton CO_2 when the electricity generated by the PV system on the roof is used. The fabrication and installation of the PV solar roof causes an emission of 1.7 ton CO_2. The installation of the PV solar roof cost €22.000,-.

Since in section 14.4, it was found that the solar panel system on the roof of Irmão does not generate enough electricity to cover the full annual electricity demand of Irmão, the solar panel path is required to be installed. The solar panel installation over the walking path is given in detail in section 14.5. The solar walking path consist of three sections because the walking path consist of three straight sections. The walking path solar panel system consist of a wooden construction on where the solar panels are mounted. The solar panels are mounted with a 10 °tilt angle to increase the electricity generation per meter. Three solar panels are mounted side by side. This leads to an annual electricity generation of 1.79 MWh/unit for section one, 1.78 MWh/unit for section two and 1.76 MWh/unit for section three. The difference in annual production is due to the difference in azimuth angle of the parts. The solar path units are chosen to be placed as close as possible to Irmão because these units have a positive image that should be linked to Irmão. This demonstrates that they are actively contributing to reducing their environmental footprint.

Finally, the Balance of System is given in section 14.6. This section contains the inverter selection, cable selection and mounting system. For the different solar panel sections, different inverters are selected from the Fronius Symo datasheet in figure C.4. The final selection of the inverter will be done in chapter 15. The mounting system selected for the PV solar systems is the Schletter mounting system because it can be installed on the corrugated iron roof of Irmão. The next chapter, chapter 15, will now look at which elements are applied in the *Improved scenario* and in the *Future scenario*. It will look at the exact costs and savings in terms of CO_2 and NO_x emissions.

15 Energy system scenarios

This chapter elaborates on the energy system for the two different scenarios. Besides, this chapter provides an overview of the level of sustainability of the two scenarios, compared with the current situation of in the energy system of Irmão. In section 15.1, the improved Irmão energy system is worked out, taking into account the existing boundaries of Irmão. In section 15.2, the future Irmão energy system is discussed. In this design, the current limits of Irmão are abandoned and the restaurant is designed from scratch in terms of energy supply and consumption. Both designs elaborate on the gas and electricity supply of Irmão.

15.1. Improved Irmão energy system

The energy system for the Improved Irmão concept is designed to achieve improvements in sustainability within the boundaries of the current situation. For this reason, it is chosen to install an energy system with a solar panel installation on the roof of Irmão and a PVT system to replace the gas water heater. The infrastructure of the Improved Irmão energy system is given in figure 15.1.

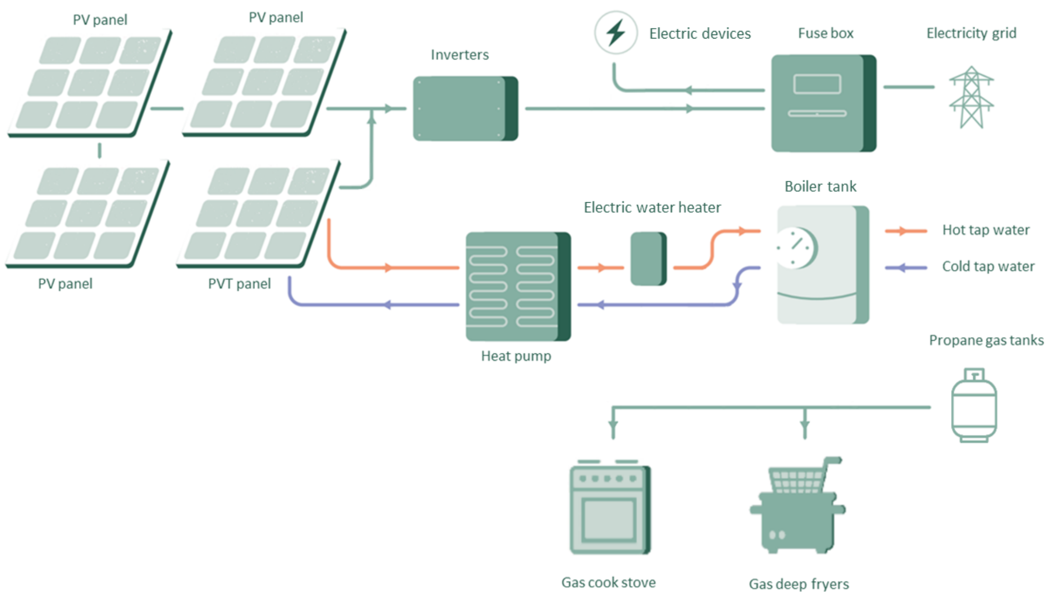


Figure 15.1: Improved energy infrastructure of Irmão.

Here, the only gas devices are the gas cook stove and the gas deep fryers. The gas water heater is replaced with the PVT system, which is explained in section 14.1.3. The electricity consumption is partly covered by the electricity generated with the PV solar system on the roof of Irmão. The remaining electricity demand is covered by electricity from the grid.

15.1.1. Improved Irmão gas system

In the Improved Irmão energy system design, only the gas water heater will be replaced by the PVT system. Only the gas water is replaced by the PVT system, because this will have the highest reduction in CO_2 emission compared with the other gas devices due to the high efficiency of the PVT system. Besides, the owners of Irmão are most willing to replace the currently used gas water heater. The gas cook stove is maintained, because currently the kitchen staff prefers to cook on gas. The gas deep fryers are maintained because the currently used gas deep fryers are the devices where the least emissions reduction can be achieved.

The PVT system is explained in section 13.2.3. Here, the conclusion is made that the PVT system has a daily energy consumption of 9.06 kWh which is a reduction of 75% compared with the gas water heater. The remaining data of the PVT system can be found in table 14.3 and table 14.4. The total gas consumption of the Improved Irmão Scenario is given in table 15.1. In this table, the annual gas consumption in kWh, annual emission of CO_2 and the annual gas propane consumption cost are given. The gas consumption is decreased with 33% compared with the current gas consumption of Irmão.

Table 15.1: The annual gas energy consumption, annual gas CO_2 emissions and annual cost of gas in the Improved Irmão energy system.

Energy carrier	**Energy consumption (MWh/year)**	**Emission CO_2 (ton/year)**	**Emission NO_x (kg/year)**	**Cost (€)**
Gas	22.35	5.05	0.00	€ 2.798,0

15.1.2. Improved Irmão electricity system

The Improved Irmão energy system has an electricity demand of 86.04 MWh per year. This is 6.4% higher than the annual electricity demand of the current situation. This is because of the extra electrical devices of the new water system, the new device from waste management and the electrical devices of the PVT water heating system.

In the Improved Irmão energy system, panels are only installed on the roof of Irmão. A total of 62 panels can be installed according to the *Base configuration*. Figure 15.2 shows the electricity generation pattern based on the incoming irradiance for the year 2020, from Meteonorm. Also, a second degree polynomial is plotted through the data to show the trend.

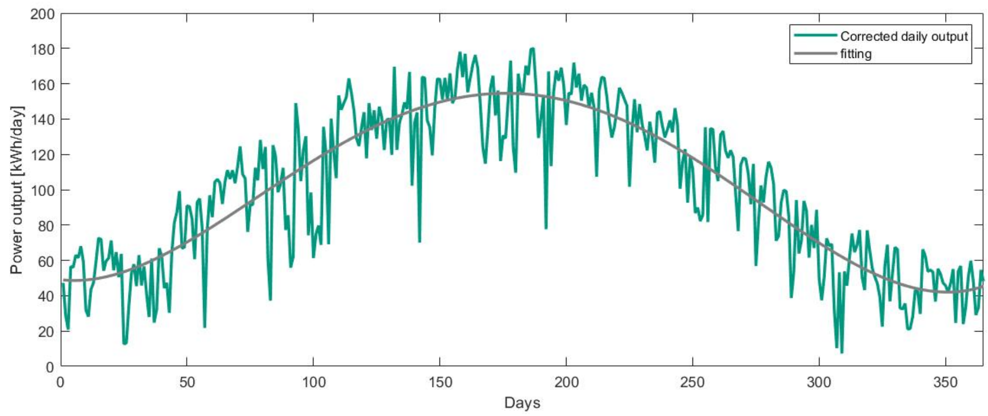


Figure 15.2: Power output of the rooftop PV solar system

The graph clearly shows that the daily electricity generation is higher in summer than in winter. In summer, on average, around 150 kWh per day can be generated, with peaks of up to 180 kWh per day. In winter, however, this is only 50 kWh on average. Combining the weekly generation results in an annual generation of 36.6 MWh. This includes the PV panel efficiency, temperature gradient efficiency, inverter and cable losses. The temperature gradient efficiency, and inverter and cables losses where not included in the calculations performed in section 14.3. The annual electricity generated by the PV solar system on the roof is 45.2% of the annual electricity demand of Irmão. The other 54.8% of the electricity demand will be covered by the electricity grid. Figure 15.3 provides a visualization of what Irmão will look like with the solar panels on the roof.

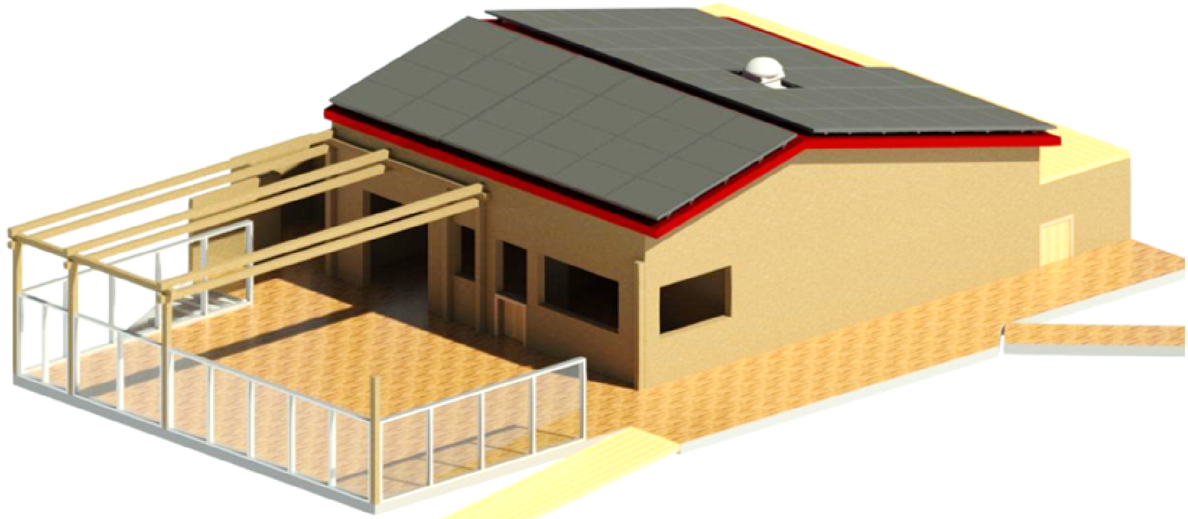


Figure 15.3: Revvit of the Improved Irmão Energy System.

The inverter selection for the the seaside roof and backside roof sections is based on the *Base configuration*. The seaside section contains two strings of 13 panels in series and the backside contains two strings of 19 solar panels in series. The given configurations result in the values depicted in figure C.5 of Appendix C. Based on these values, the Fronius Symo 12.5-3-M is selected for the seaside section and the Fronius Symo 15.0-3-M for the backside section. The cost of the Fronius Symo 12.5-3-M is €1.949,- and the Fronius Symo 15.0-3-M has a cost of €1.979,-.

15.1.3. Overview Improved Irmão Energy System

The Improved Irmão energy system realises a gas consumption decrease of 33% as the PVT system heats the largest amount of water, making a traditional gas boiler unnecessary. This reduction in gas consumption results in reduced CO_2 emissions of 2.2 ton/year and a reduction in NO_x emissions of 361 kg/year. Also, 45.2% of the annual electricity requirement is self-generated. This results in a total of 36.6 MWh less needs to be purchased from the grid, which results in a CO_2 reduction of 8.8 ton. In total, the Improved Irmão Energy System reduces emissions by 9.8 ton/year of CO_2 and 361 kg/year of NO_x compared with the current energy system emissions. The fabrication of PV Solar panels leads to the emission of CO_2. This is according to literature 50 g/kWh produced (GVEC, 2021). The fabrication of the PV Roof solar panels therefore has an emission of 1.830 ton CO_2, which is 18.7% of the annual CO_2 emission reduction of current energy system in the first year. In the second year the CO_2 emissions from producing the panels is zero.

The total cost of realising the Improved Irmão Energy System amounts to €46.700,- as depicted in table 15.3. A full cost overview consisting of the components of the PV roof system is given in figure C.6 and C.7 of Appendix C. Because less electricity needs to be taken from the grid and less gas needs to be purchased, there are also financial benefits. Annually, it is possible to save €5.512,- including maintenance costs. Assuming a discount rate of 4%, a discount payback period of 10 years is estimated. This is in line the values obtained from the literature where a PV and PVT system located in England with less irradiance, has a discounted payback period of 12 years (Herrando and Markides, 2016).

Table 15.2: Emission overview Improved Irmão energy system.

	Energy consumption (MWh)	**Emission CO_2 (ton)**	**Emission NO_x (ton)**	**Cost (Euro/year)**
Grid electricity	49.4	11.9	0.0	€ 7.950,-
PV roof electricity	36.6	0.0	0.0	€ 0,-
Gas	22.4	5.1	0.0	€ 2.800,-
Total	108.4	17.0	0.0	€ 10.750,-

Table 15.3: Financial overview Improved Irmão Energy System.

Costs	**Year 0**	**Year 1-25**
Investment	€ 46.300	€ -
Fixed costs	€ -	€ -
Maintenance cost	€ -	€ 770
Savings	€ -	€ 6.280
Cash flow	€ -46.700	€ 5.510
Discounted Payback period (r=4%)	10 year	

15.2. Future Irmão energy system

The energy system for the Future Irmão Scenario is the most sustainable design possible based on the solutions of Chapter 14. Therefore, the Future Irmão energy system contains the PV system on the roof of Irmão and the solar path PV system to generate enough electricity to cover the total annual electricity demand of Irmão. Besides, the Future Irmão energy system contains the PVT system to replace the gas water heater, an induction cook stove to replace the gas cook stove and electric deep fryers to replace the gas deep fryers. The infrastructure of the Future Irmão energy system is given in figure 15.4. Comparing energy infrastructure in figure 15.4 with the energy infrastructure in figure 15.1, it can be noted that the gas tanks are eliminated and more PV panels are added.

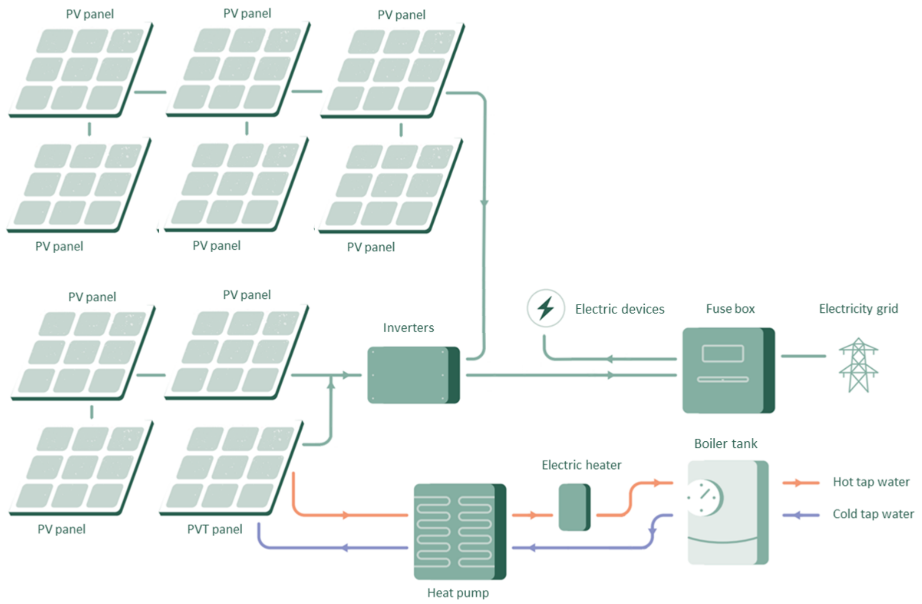


Figure 15.4: Future energy infrastructure of Irmão.

15.2.1. Future Irmão gas system

The Future Irmão energy system does not contain any gas devices anymore. The total annual gas consumption, CO_2 emission from gas consumption and NO_x emission from gas consumption are 100% reduced. The alternative electrical devices are defined in section 14.1. The alternatives have an electricity consumption of 14.42 MWh per year which is added to the total annual electricity consumption of Irmão.

15.2.2. Future Irmão electricity system

In the Future Irmão energy system, in addition to the panels on the roof, the PV Solar Path is also implemented. From section 15.1.2, it is known that 36.6 MWh of electricity can be generated annually by the PV system installed on the roof. In order to supply the full 100.8 MWh electricity demanded, it is necessary for the solar path to supply 64.2 MWh annually. In order to have the PV Solar Path positioned as close to Irmão as possible, the first section of the PV Solar Path will be installed on section 1 of the walking path. After this, the solar path will be extended towards the car park until it is able to supply the entire demand. Per solar path unit (3 solar panels side by side as discussed in section 1) 1.79 MWh of electricity can be generated annually. According to these findings, a total of 25 solar path units need to be installed on the first section, as this is the maximum amount of panels that can be installed on section 1. On the second section, an additional 11 solar path units need to be installed, as they produce 1.78 MWh annually. The annual generation of electricity of the solar roof installation, solar path installation and the combined generation are presented together with the consumption in figure 15.5.

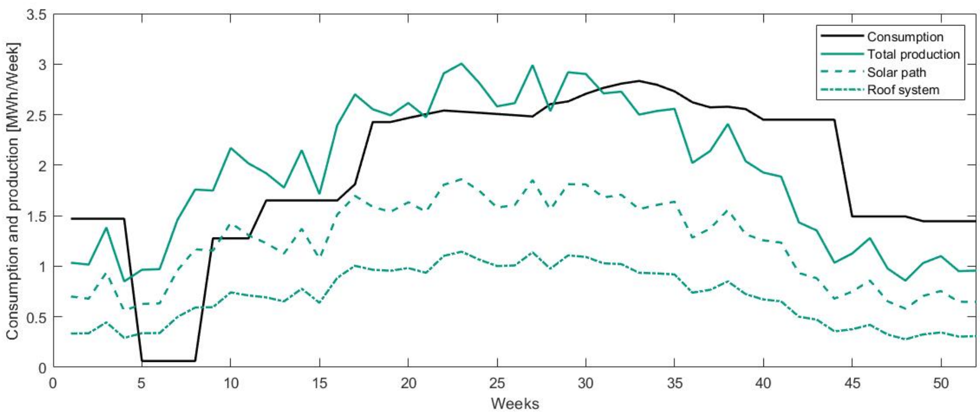


Figure 15.5: Consumption and generation of electricity

As the electricity consumption was determined per week, it was decided to present the electricity generation per week as well. Again, the figure clearly shows that more electricity is generated per week during summer than during winter. During the summer months the total PV system can generate on average 2.75 MWh of electricity per week. During the winter months this is only 1 MWh per week. Combining all weekly generation results in an annual generation of 102.8 MWh. This is sufficient to cover the annual electricity demand of 100.8 MWh. However, figure 15.5 shows that the required electricity is not always delivered when needed. Figure 15.6 shows per week whether there is a shortage or surplus of produced electricity that week.

When the bars in figure 15.6 are positive, this indicates that there is an energy surplus. When the bars are negative, there is an energy production deficit. During the first half of the year it can therefore be said that the PV system generates more than the restaurant consumes. However, because the system, as explained in section 5, is a grid tied system, this is not a problem.

The inverter selection for the the seaside roof and backside roof sections is the same as in section 15.1. The PV Solar Path inverter selection is again based on the configuration of the solar panels. The first section of the PV Solar path contains three strings of 19 panels in series and one string of 18 panels in series. The second section of the PV Solar Path consist of one string of 17 solar panels in series and one string of 16 solar panels in series.

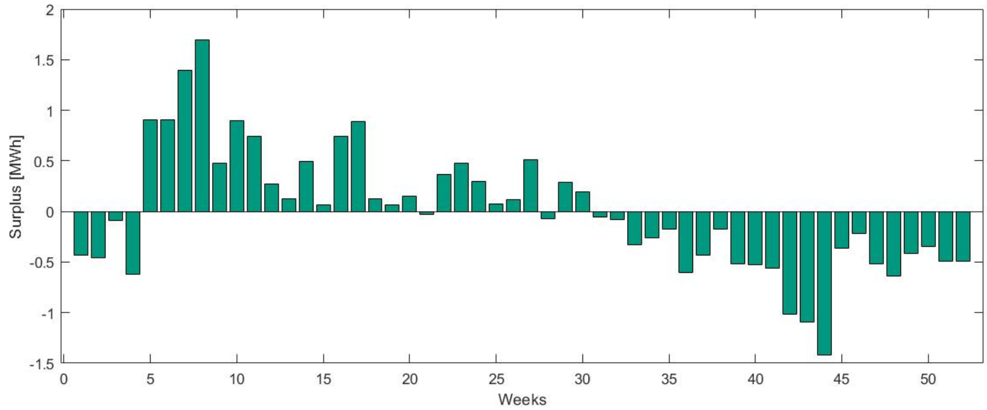


Figure 15.6: Consumption and generation of electricity.

The given configurations result in the values depicted in figure C.5 of Appendix C. Based on these values, two Fronius symo 15.0-3-M inverters are required for the first section of the PV Solar Path and one Fronius symo 15.0-3-M inverter is selected for the second section of the PV Solar Path. The cost of the Fronius symo 15.0-3-M is €1.979,-. Figure 15.7 presents a visualisation of the Future Irmão Scenario.

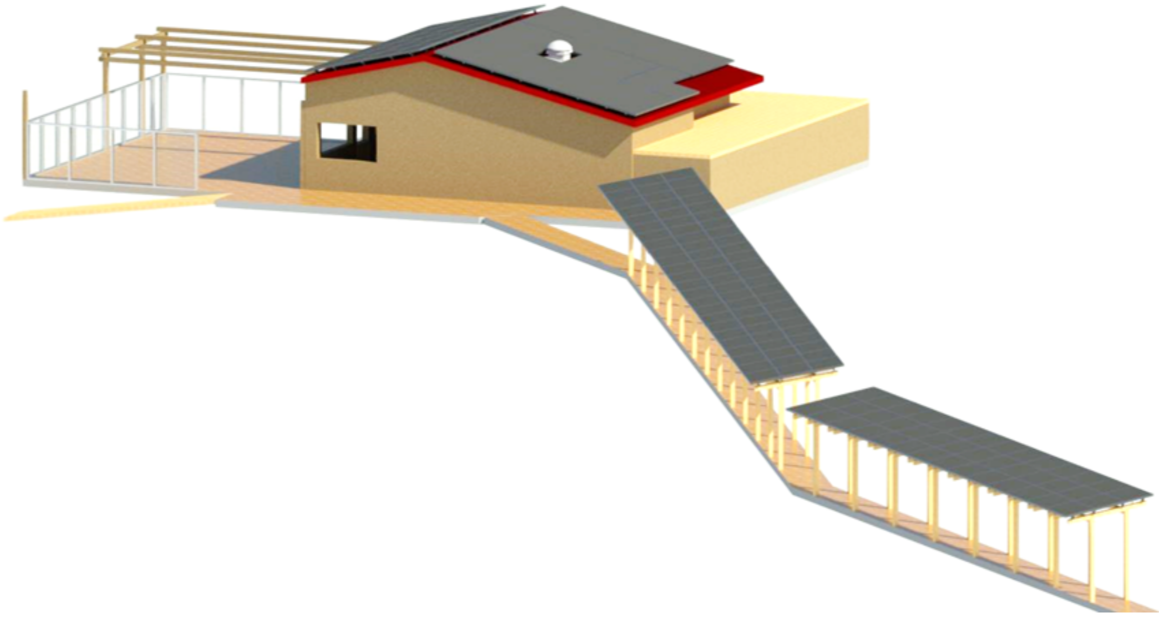


Figure 15.7: Revvit of the future Irmão energy system

15.2.3. Overview Future Irmão energy system

The Future Irmão Scenario realises a gas consumption decrease of 100% as all the gas consuming devices are replaced for electric devices. This reduction in gas consumption results in reduced CO_2 emissions of 7.3 ton/year and a reduction in NO_x emissions of 361 kg/year compared to the current situation. Also, 100% of the annual electricity requirement is self-generated. This results in a total of 80.9 MWh less needs to be purchased from the grid compared with the current situation. Besides, a CO_2 reduction of 19.5 ton/year is achieved by not consuming electricity from the local electricity grid. In total, the Future Irmão Energy System reduces CO_2 emissions by 26.8 ton/year and 361 kg/year kg of NO_x. The fabrication of PV Solar panels leads to the emission of 50 g/kWh CO_2, only in the first year of operation, as mentioned in section 15.1.3. The fabrication of the PV Roof and PV Path solar panels therefore has an emission of 5.04 ton CO_2, which is 19% of the annual reduced CO_2 emission of the Future Irmão energy system.

The total cost of realising the Future Irmão Energy system amounts to €125.500,- as shown in table 15.5 and consists of the components presented in figure C.7 of Appendix C. As no electricity needs to be taken from the grid and zero gas needs to be purchased, there are also financial benefits. Annually, it is possible to save €15.260,- which includes maintenance costs. Assuming a discount rate of 4%, the investment will be recovered in 10 years. This is similar to the payback period of the Improved Irmão Energy System and similar to literature (Herrando and Markides, 2016).

Table 15.4: Emission overview Future Irmão Energy System.

	Energy consumption (MWh)	**Emission CO_2 (ton)**	**Emission NO_x (ton)**	**Cost (euro/year)**
PV roof electricity	36.6	0.0	0.0	€ 0,-
PV path electricity	64.2	0.0	0.0	€ 0,-
Gas	0	0.0	0.0	€ 0,-
Total	100.8	0.0	0.0	€ 0,-

Table 15.5: Financial overview Future Irmão Energy System.

Cost	**Year 0**	**Year 1-25**
Investment	€ 125.500	€ -
Fixed costs	€ -	€ -
Maintenance cost	€ -	€ 1.770
Savings	€ -	€ 17.030
Cash flow	€ -125.500	€ 15.260
Discounted Payback period (r=4%)	10 years	

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Finalization

16

Results integrated design

This chapter aims to present the results of the merged designs. That is, the combined results of the designs concerning the water system, waste management and the energy system. In this chapter, first the results of the designs in which additions have been made to the current system to improve the sustainability of Irmão are presented, this design is called *Improved Irmão Scenario*. The same has been done for the designs from which the restaurant can be built from scratch, referred to as *Future Irmão Scenario*.

16.1. Improved Irmão Scenario

The *Improved Irmão Scenario*, aims at adapting Irmão's current Water system, Energy system and Waste management while taking account the framework of the current restaurant. The items that are included in this design are presented in table 16.1. The budget and savings of this design are shown in the financial overview of Table 16.1. The expected results regarding water use, propane use, CO_2 emissions, NO_x emissions and CH_4 emissions are presented in Table 16.5. It should be noted that these are only the emissions from the processes investigated, namely those related to water use, electricity generation, propane combustion and organic waste treatment.

Table 16.1: Items that are included in the design that aims to improve the sustainability of Irmão within the framework of the current situation.

Items improved water system Irmão	**Items improved energy system Irmão**
• Implementation of water saving equipment	• Replace gas boiler by PVT system
• Installation of vacuum toilets	• Placement of PV panels
• Installation of waterless urinals	
• Implementation of circularity	
Items improved waste system Irmão	
• Placement of underground waste containers	
• Implementation of a composting machine	

Table 16.2: Financial overview of the design Improved Irmão Scenario

Financial overview 'Improved Irmão Scenario'	**Year 0**	**Year 1-25**
Investment	€ 79.100	€ -
Fixed costs	€ -	€ 300
Maintenance costs	€ -	€ 1000
Savings	€ -	€ 11.300
Cash flow	€ -79.100	€ 10.000
Discounted payback time (r=4%)	10 year	

16.2. Future Irmão Scenario

The second scenario, *Future Irmão Scenario*, in which Irmão must relocate, offers the possibility to make a design from scratch. The items that are included in this design are presented in table 16.3. The budget and revenues of this design are shown in the financial overview of Table 16.1. The expected results regarding water consumption, propane consumption, CO_2 emissions, NO_x emissions and CH_4 emissions are presented in Table 16.5. It should be noted that these are only the emissions from the processes investigated, namely those related to water use, electricity generation, propane combustion and organic waste treatment.

Table 16.3: Items that are included in the design that aims to improve the sustainability of Irmão, in case that the restaurant can be rebuild from scratch.

Items future water system Irmão	**Items future energy system Irmão**
• Implementation of water saving equipment	• Replace gas boiler by PVT system
• Installation of vacuum toilets	• Placement of PV panels
• Installation of waterless urinals	• Replace gas cook stove by induction cook stove
• Implementation of circularity	• Replace gas deep fryer by electric deep fryer
• RO filtration of water from the borehole	
• Construction of biogas plant	
Items future waste system Irmão	
• Placement of underground waste containers	
• Construction of biogas plant	

Table 16.4: Financial overview of the design 'Future Irmão Scenario'

Financial overview 'Future Irmão Scenario'	**Year 0**	**Year 1-25**
Investment	€ 170.400	€ -
Fixed costs	€ -	€ 700
Maintenance costs	€ -	€ 2.200
Savings	€ -	€ 26.700
Cash flow	€ -170.400	€ 23.800
Discounted payback time (r=4%)	9 year	

An overview of the expected results in terms of improving the sustainability of the two scenarios compared to the sustainability of the current restaurant is presented in the figure 16.5. The sustainability is quantified according to five categories, namely the amount of annual water consumption, the amount of propane use, CO_2 emission, NO_x emission and CH_4 emission. The values in the table are summations of the results obtained in chapters 8, chapter 10 and chapter 14, where it is explained in more detail. An extensive conclusion and interpretation of the results are discussed in chapter 17 and chapter 18.

Table 16.5: Total overview of consumption, emission and cost for each system.

	Current situation		**Improved Irmão Scenario**	**Reduction (%)**		**Future Irmão Scenario**	**reduction (%)**
Annual water consumption [m^3\yr]	2313		1092	53%		1092	53%
Annual propane consumption [kg\yr]	2421		1622	33%		0	100%
Annual CO_2 emission [kg\yr]	29741		17950	39%		462	98%
Annual NO_x emission [kg/yr]	382		0	100%		0	100%
Annual CH_4 emission [kg/yr]	190		38	79%		38	79%

17 Conclusion

The goal of this project was to provide Irmão beach restaurant with an advice on how to establish and operate a more sustainable beach restaurant, in present or future times.

The analysis of the current state of sustainability of Irmão has revealed areas where gains can be made. Regarding the sustainability of Irmão's water system, it can be concluded that there is little room for improvement in terms of emissions, as the water use is expected to cause an emission of 182 kg CO_2 per year. However, it has become clear that the current system is not water-efficient. For example, no water is reused and there are two devices with a relatively high consumption, the toilets (768 m^3/yr) and the taps inside Irmão (859 m^3/yr). In total, according to the models used in this study, 1108 m^3 of water is received per year from the public grid and 1205 m^3 is extracted from the ground. In addition, there is the problem that the waste water storage tank is too small for the supply of waste water, so that the tank has to be emptied several times a day. Since this does not always happen in time, it occasionally occurs that the wastewater overflows and ends up in the dunes, which has harmful consequences.

The production of plastic, paper, glass and rest waste is 18.2 kg, 27.1 kg, 17.0 kg and 119.2 kg per day, respectively. The categories plastic, paper and glass are beyond the scope of this study, because of the owners preferences concerning hygiene and comfort. Within the rest waste category, the focus is on making the organic waste that is currently produced more sustainable. This is about 50 kg per day and results in approximately 12.5 tonnes per year. This results in emissions of 2.8 tonnes of CO_2 and 190 kg CH_4 if it ends up in a landfill. In terms of waste treatment, the problem is that there is not enough capacity in the current waste containers. Subsequently the waste is placed next to the containers, resulting in nuisance for visitors in the form of smell and appearance.

Regarding the analysis of the current energy system of Irmão, it was concluded that the energy system causes a considerable amount of CO_2 and some NO_x emissions, namely 26.8 tonnes of CO_2 and 382 kg of NO_x per year. These emissions can be traced back, in large part, to the generation of electricity in power stations and, in part, to the burning of propane in the restaurant. These are therefore the two main components that are included in the proposed scenarios.

Two scenarios were made to improve the sustainability of Irmão. The first scenario, called *Improved Irmão Scenario*, aims at adapting Irmão's current water system, energy system and waste management. The scenario takes into account the framework of the current restaurant. The second scenario, called *Future Irmão Scenario*, was made in case the restaurant has to move to a new location, which offers the possibility to start from scratch.

Improved Irmão Scenario

The *Improved Irmão Scenario* contains four changes in the fields of the water system, two changes in the field of the waste system and also two changes in the field of the energy system. According to the method applied in this study, implementing four types of water-saving devices, installing five vacuum toilets, fitting three waterless urinals and implementing circularity will significantly reduce the total water consumption, namely by 53%. In addition, it is estimated that these measures will reduce the need to empty the wastewater storage tank by 53%, thus reducing CO_2 emissions from the waste water collecting truck. These adjustments to the water system have an estimated investment cost of €19.900, while the net annual savings are estimated at €4.500. Although this solution contribute little in terms of reducing emissions, there is significant benefit in terms of reducing water consumption.

In terms of waste management, this scenario contains two components, namely a composting machine and four underground waste containers. The compost machine can be used to turn different types of organic waste into compost by aerobic bacteria. The carbon in compost is very stable, which leads to less conversion of carbon into CO_2. Besides, the aerobic bacteria prevent the forming of CH_4. This results in the avoidance of 2.26 tonnes of CO_2 and 147 kg of CH_4 being emitted annually. The cost of this machine is €12.500. Furthermore, it was decided to add underground containers to the scenario in order to prevent waste from spilling into nature in the car park. The cost of the underground containers is €50.000 in total, which can possibly be financed by the government. Although there is not much benefit from a financial point of view, placing the composting machine and underground containers is very beneficial in terms of emissions and pollution of the direct environment respectively.

Regarding the modification of the energy system, the scenario to make the current energy system more sustainable includes the following items. Firstly, the gas boiler has been replaced by a system that, in addition to generating energy, is also capable of acting as a heat exchanger and thus functions as a water heater. This system that is called a PVT system, consists of eight PVT panels on the roof, a heat exchanger, an electric water heater and a boiler tank. The study showed that by implementing the PVT system, the propane consumption of Irmão will reduce by 33%, resulting in no NO_x being emitted, as the NO_x is currently released during propane combustion in the traditional gas boiler. In addition to the PVT system, the scenario contains 54 PV panels on the roof at the same tilt and azimuth as the roof. The combined system of PV and PVT can cover 45.2% of the energy demand of Irmão. Since this amount does not need to be obtained from the grid, the CO_2 emissions will be reduced by 9.8 tons per year. The investment cost of the combined PV and PVT system is €46.700 and the net savings are expected to be €5.500 per year.

In total, the *Improved Irmão Scenario* is expected to result in 11.6 tonnes less CO_2, 152 kg less CH_4 and 382 kg less NO_x being emitted annually. The investment cost to realise this scenario is €79.100. However, the annual savings are estimated to be €10.000 per year, resulting in a discounted payback period of ten years.

Future Irmão Scenario

In case the restaurant must be build at the new location due to legislation, the opportunity arises to compose a design from scratch. In the *Future Irmão Scenario*, a number of additions or adjustments are made in the fields of water, waste and the energy system in comparison to the '*Improved Irmão Scenario*'.

In order to make the water system of the *Future Irmão Scenario* as sustainable as possible, water-saving equipment, vacuum toilets, waterless urinals and circularity will be used, just like in the *Improved Irmão Scenario*. This will already yearly save €4.500 and the investment costs €19.900. In addition, the connection to the public network will not be needed, since the water obtained from the borehole is sufficient. To ensure that this water is drinkable, a pressurised reversed osmosis filtration system with a capacity of 1000 L/hr will be installed. With a storage tank and centrifugal pump to pump to the users, this whole investment costs €7.700. This will save Irmão 1108 m^3 of water from the grid, which is equivalent to €4.830 a year.

In addition, a biogas plant will be implemented, which is considered to be a sustainability of both the water system and waste management. This biogas plant can convert 20 tonnes of organic waste and human manure from the vacuum toilets via anaerobic digestion into 1050 m^3 biogas (methane) and a slurry, comparable to compost. This is equivalent to 7.5 MWh energy, to be used for the gas heaters, since it is an insufficient amount to cover the demand of the gas cook stove, gas water heater or gas deep fryers. It will also reduce CO_2 and CH_4 emissions, 2.34 tonnes and 148 kg respectively, compared to the emissions from a landfill. The size is about 6 m^3 and the investment costs €15.000 with €120 maintenance costs per year. Besides the biogas plant, the underground waste containers discussed in the *Improved Irmão Scenario* are also applied in the waste management of the *Future Irmão Scenario* to solve to waste problem on the parking area.

To make the energy system of Irmão sustainable in the *Future Irmão Scenario*, the solutions already applied in the *Improved Irmão Scenario* will be used again. These are the replacement of the gas boiler by a PVT system and the installation of PV panels on the roof of Irmão. With this scenario implemented, 2.2 ton CO_2 and 361 kg of NO_x are emitted. This will yearly save €5.500 and costs €46.700. In addition, two more solutions will be implemented. First, all gas devices, except the gas heaters, will be replaced by alternative electric devices. Besides the already replaced gas water heater, also the gas cook stove and gas deep fryers will be replaced by respectively an induction cook stove and electric deep fryers. This will reduce the emissions of 7.3 tonnes of CO_2 and 361 kg of NO_x per year produced by the gas-consuming appliances by 100%. Together, this costs €3.700 and saves €870 annually. Furthermore, the number of PV panels will be further expanded to ensure that all the energy required by Irmão is generated by itself. This will be realised by constructing a PV Solar Path. This path consists of 36 Solar Path Units (3 PV panels per unit) and will be built over the existing footpath from the parking area to Irmão. With a total number of 162 PV and 8 PVT, 102,8 MWh per year will be generated, which is sufficient to cover Irmão's total electricity demand of 100,8 MWh per year. This Solar Path costs €75.300 adding up to a total investment costs of the *Future Irmão* energy system will than be €125.500 and yearly savings €15.300.

In total, the *Future Irmão Scenario* is expected to result in emitting 29.2 tonnes less CO_2, 152 kg less CH_4 and 382 kg less NO_x annually, compared to the current situation. The investment cost to realise this scenario is €170.400. However, the annual savings are estimated to be €23.800 per year, resulting in a discounted payback period of eight years.

The question on how Irmão can become more sustainable in terms of the water system, waste management and the energy system can be answered as follows. Regarding the water system, reducing the total water consumption by implementing water efficient devices and water circularity. As for waste management, by processing waste so that it does not end up in landfills or in nature. Regarding the energy system, by using as little propane as possible and by generating electricity with solar panels, to cover the energy demand of Irmão.

18

Discussion

Since theoretical knowledge is applied to real-life situations and it was agreed beforehand to work within a certain scope, there are several limitations to the research. These limitations are addressed and discussed in this section. For ease of reading, recommendations to overcome these limitations are provided directly.

Material externalities
In order to achieve more sustainable operations, several suggestions have been made in this study. These suggestions often involve the purchase and implementation of new advanced equipment. For the solutions, either specific products or entire concepts were recommended. The products recommended were those that offered the best results in the area in which they were used, which often resulted in technologically advanced products, where the sustainability of the products themselves was not examined. The sustainability of a product can be viewed in different ways. Three important aspects are the material these products are made of, the way the product is made and the location where the product is made. Regarding the material, for example, it is desirable that no rare materials are used or that the obtaining of this material is not labour-intensive. With regard to the manufacture of the product, it is advantageous if, for example, this is not energy-intensive. And regarding location, when the purchased products are transported over a long distance, this involves emissions and pollution. If the distance transported is too large, this would eventually no longer outweigh the improvement that the purchased product brings. In that case, the final result will be negative. It is therefore recommended to take these considerations into account when purchasing the recommended products. When buying a specific model, it is recommended to examine how it was made, where it is made from and where it is made. In a perfect world it would be produced locally, in a sustainable manner, and from sustainable materials.

With the same reasoning as above, it should be mentioned that when the restaurant has to be relocated and/or expanded, the construction materials used must be carefully selected. Here again, the type of material, the production method and the origin of the material are important. Also, recycling materials from the existing building is environmentally beneficial. It is therefore recommended that a follow-up study be conducted to determine which materials are the most beneficial, where these materials are sourced, and which materials can be recycled to build or expand the restaurant.

Cost of implementation and feasibility
In proposing the various solutions to make Irmão more sustainable, several criteria, including cost, were considered. However, the degree to which a solution contributed to making Irmão more sustainable was ultimately decisive. This resulted for the *Future Irmão Scenario* being priced at €170,380. That is why it is worth mentioning that the final scenario can also be carried out in parts, should the total amount be too much to invest all at once. Please note that the biogas plant contributes to both waste and water and energy, so if you choose not to install it, the benefits it provides will be lost in all three areas.

If Irmão chooses to fully implement the concept of present Irmão in all areas, it should be noted that the total payback time is 10 years. Since it is uncertain at the moment how long Irmão can remain at its present location, it is wise to sort this out first. Suppose that Irmão will have to move within a year, they would be better off looking at the concept for future Imrão. Suppose they are told they can stay put for a period of five years, then it would be wise to implement solutions that they can take with them to the new location after those five years. For example, solutions such as solar panels, pumps and filters can easily be moved and used again.

There is also another way to reduce the amount of financial capital that the owners of Irmão have to spend to realise the final design of future or the improvements of present Irmão. Namely by applying for subsidies from the municipality. As a conversation with the owners revealed that not only Irmão, but also the municipality wishes to become more sustainable and is therefore prepared to support projects that lead to sustainability by means of subsidies. That is why one of the recommendations for further research is to find out exactly which subsidies can be applied for. Since applying for subsidies is a time-consuming process, exacerbated by the language barrier, it was decided to leave it out of the scope of the current study.

The menu

Something that was beyond the scope of this study, but which has a great influence on the environment, is the food served. Both the type of food consumed and the way food is made . Therefore, for a restaurant that wants to be as sustainable as possible, it is indeed important. For example, the production of one kilo of beef leads to the emission of almost 100 kg of CO_2, this number takes into account other greenhouse gases by expressing them in CO_2 according to their relative warming effect (Poore and Nemecek, 2018). If one compares this with an annual reduction of 182 kg CO_2 due to the solutions included in the *Future Irmão Scenario* in terms of water management, it can be seen that there is a lot of profit to be made by adjusting the menu. Furthermore, the use of local products can minimise CO_2 emissions from product transport. The tricky part is that Irmão would like to keep its customers and therefore does not want to compromise on the taste and quality of the food. Furthermore, they would like to be able to meet the demand of their customers, which makes it difficult to adjust the menu. This was the reason why it left outside the scope of this research. If Irmão would desires to take a further step forward in the field of sustainability, then it is recommended to conduct research into the field of the food served. Then it is advisable to look for alternatives to meat and fish on the menu, as these products lead to the highest greenhouse gas emissions. Also, using local products is recommended. Furthermore, it is wise to talk to their customers, in order to find out for which products or dishes they can put alternative dishes on the menu, without losing their customers.

Data

As mentioned before in chapter 5 this research has been carried out in limited period of time. Thus, available monthly bills, measurements and the cover model were used to arrive at annual data. This has led to several uncertainties that will be mentioned below.

First, the data regarding the number of covers, which was used to compose the cover model. The amount of covers, is the amount of bills of the deck that have been closed on a day, the bill on the beach are therefore not represented. Together with the owner, an estimate was made of the total amount of bills from the beach and deck together, in order to get realistic picture of the situation. Furthermore, a cover is a closed receipt rather than the exact number of people, whereas the number of visitors is interesting for making calculations and estimates. With advice from the owners of Irmão, it was decided that one receipt equals 2-3 visitors. And finally, because of COVID-19, Irmão was only open from week 14 to 37, therefore data on the number of covers are only available from these weeks. Based on a market research done by the owners themselves, an estimation of the remaining weeks was made as can be read in section 6.2. Taking the above into account, it can be concluded that there are several assumptions in the cover model. Although this data is likely to be a good reflection of reality and can be used as a reference to carry out the study, it cannot be said it is the absolute truth .

Then, regarding that the measurements have been carried out over six weeks in the months of September and October. Because these measurements were taken by mostly Irmão staff and were not automated, measurements were not executed with the highest precision. For example, water and electricity readings were usually taken around noon, but sometimes later. This again leads to inaccuracies in the final data.

Finally, the measurements were taken daily, which is certainly accurate enough for water consumption and the amount of waste produced. However, for the energy system related topics even more frequent data would be desirable, for example per hour or even minute. This would be beneficial in order to be able to calculate the required peak-power more precisely.

As mentioned earlier, the annual data obtained provides a good basis for proposing solutions that will lead to sustainability improvements at Irmão. Even though the data was not completely accurate, it clearly showed the areas where the most benefits could be achieved. However, consistent measured data over a full year, during which Irmão is fully open, would allow for more accurate assessments and more precise advice. Therefore, it is recommended that the study be repeated, but then with consistent data measured over a full year, and with hour to hour data to analyse the use of energy. It would then be interesting to see to what extent the cover model is accurate in combination with limited data, so that this principle can be applied in other researches.

Individual versus global result

Should Irmão decide to realise the *Future Irmão scenario*, great progress will be made in terms of sustainability. Realising it would mean the emission of greenhouse gases will be reduced by great amount. As for the possibility of greater sustainability, Irmão would then be at its limit within the scope of this study. Unfortunately, it must be recognised that reducing the emissions and production of waste of a single restaurant will not, of course, solve the problem of global warming. Nor will recycling water from a single restaurant solve drought worldwide. Even in the local environment, this reduction in emissions, waste and water use will not be noticed. A difference can only be made if many parties take part.

This can be achieved if Irmão or this project can inspire people and other restaurant to become aware of the possibilities of becoming more sustainable. An effective way that is currently very applicable is to promote and inspire through social media. By promoting the sustainability of the restaurant on the internet, it can not only attract more customers, but also be an example for restaurants all over the world. In addition, showing customers in the restaurant that they are in a sustainable restaurant can make these people inspired or inspire others. Besides showing people the solar panels on the path, there are other ways to show this. For example, by putting up signs or mentioning it on the menu. An example of such a sign would be one by the toilets indicating that the flush water comes from recycled water. Another possibility would be mentioning on the menu that all food served is prepared using electricity generated by solar energy.

Another thing that can contribute to more restaurants around the world becoming sustainable is lowering the threshold to do so. Since it is currently a time-consuming process to investigate how a restaurant can become more sustainable, it would be interesting to investigate how this can be done easier and faster. For example, it could be examined whether a template could be made in which restaurants themselves could fill in the data of their restaurant. The template could then identify the opportunities for a restaurant to become more sustainable. In this way the duration and therefore costs of finding out ways to improve sustainability of a restaurant can be minimized.

Today's global warming and all its attendant problems will not be solved by making a single beach restaurant more sustainable, nor will it be done overnight. This will have to come from a collective approach of which this can serve as a first step. With this study, Irmão can lead the way in terms of sustainability combined with appearance and quality as an example to others.

A

General information

A.1. Total irradiance *Matlab* clarification

To make an assessment of the annual irradiance, the direct, diffusive and reflected components of the plane of irradiance are considered. The direct component of irradiance, Gm_{dir}, is calculated by eq. A.1

$$
\begin{aligned}
Gm_{dir} &= cos(AOI) \cdot G_{Bn} \\
AOI &= cos^{-1}\big(cos(a_M) \cdot cos(a_s) \cdot cos(A_M - A_s) + sin(a_M) \cdot sin(a_s)\big)
\end{aligned} \tag{A.1}
$$

Where AOI is the angle of incidence, a_M the altitude of the module, A_M the azimuth of the module, a_s the altitude of the sun, A_s the azimuth of the sun and G_{Bn} the direct normal radiation. G_{Bn} is provided by data from Meteonorm. The reflective component, Gm_{ref}, is determined by the eq. A.2 and accounts for all the irradiance that is received by the PV module that is reflected on other surfaces.

$$Gm_{ref} = G_{Gh} \cdot \alpha \cdot (1 - SVF) \tag{A.2}$$

Where G_{Gh} is the global horizontal radiation and α the albedo of the surrounding which is assumed to be 0.2.

The diffusive component, Gm_{dif} is calculated according to the isotropic sky model and is presented in eq. A.3. It was chosen to use the isotropic sky model was used as it requires the least data input. The SVF was calculated through the skyline profile of the building and G_{Gh} is provided by data from Meteonorm.

$$Gm_{dif} = SVF \cdot G_{Dh} \tag{A.3}$$

Where SVF is the sky view factor and G_{Dh} the diffusive radiation arising form the upper hemisphere. The G_{Dh} is provided by data from Meteonorm. The total irradiance, Gm_{tot} is the combination of all aforementioned components of irradiance and is calculated using eq. A.4

$$Gm_{tot} = Gm_{dir} + Gm_{ref} + Gm_{dif} \tag{A.4}$$

A.2. Technical specifications LG370Q1C

Mechanical Properties

Cells	6 x 10
Cell Vendor	LG
Cell Type	Monocrystalline / N-type
Cell Dimensions	161.7 x 161.7 mm
# of Busbar	30 (Multi Ribbon Busbar)
Dimensions (L x W x H)	1,700 x 1,016 x 40 mm
Front Load	6,000Pa
Rear Load	5,400Pa
Weight	18.5 kg
Connector Type	MC4, 05-8
Junction Box	IP68 with 3 Bypass Diodes
Cables	1,000 mm x 2 ea
Glass	High Transmission Tempered Glass
Frame	Anodized Aluminium

Electrical Properties (STC[1])

Model		LGXXXQ1C-A5		
Maximum Power (Pmax)	[W]	370	365	360
MPP Voltage (Vmpp)	[V]	37.0	36.7	36.5
MPP Current (Impp)	[A]	10.01	9.95	9.87
Open Circuit Voltage (Voc)	[V]	42.8	42.8	42.7
Short Circuit Current (Isc)	[A]	10.82	10.8	10.79
Module Efficiency	[%]	21.4	21.1	20.8
Operating Temperature	[°C]	-40 ~ +90		
Maximum System Voltage	[V]	1,000		
Maximum Series Fuse Rating	[A]	20		
Power Tolerance	[%]	0 ~ +3		

[1] 1) STC (Standard Test Condition): Irradiance 1,000 W/m², module temperature 25 °C, AM 1.5.
2) The typical change in module effi ciency at 200 W/m² in relation to 1,000 W/m2 is -4.5 %.
3) Application Class: A, Safety Class: II.
4) The nameplate power output is measured and determined by LG Electronics at its sole and absolute discretion.

Certifications and Warranty

Certifications	IEC 61215, IEC 61730-1/-2
	IEC TS 62804-1 (PID)
	IEC 61701 (Salt mist corrosion test)
	IEC 62716 (Ammonia corrosion test)
	ISO 9001
Module Fire Performance	Class C
Product Warranty	25 Years
Output Warranty of Pmax	25 years linear warranty[1]

[1] 1) First year: min. 98 %. 2) After 2nd year: max. 0.4 % annual degradation. 3) 25 years: min. 88.4 %.

Electrical Properties (NOCT[4])

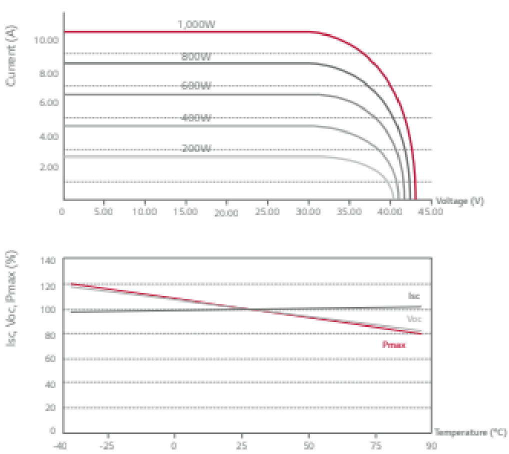
Model		LGXXXQ1C-A5		
Maximum Power (Pmax)	[W]	279	275	271
MPP Voltage (Vmpp)	[V]	36.9	36.6	36.4
MPP Current (Impp)	[A]	7.55	7.51	7.45
Open Circuit Voltage (Voc)	[V]	40.3	40.2	40.2
Short Circuit Current (Isc)	[A]	8.71	8.7	8.69

[4] NOCT (Nominal Operating Cell Temperature): Irradiance 800 W/m², ambient temperature 20 °C, wind speed 1 m/s

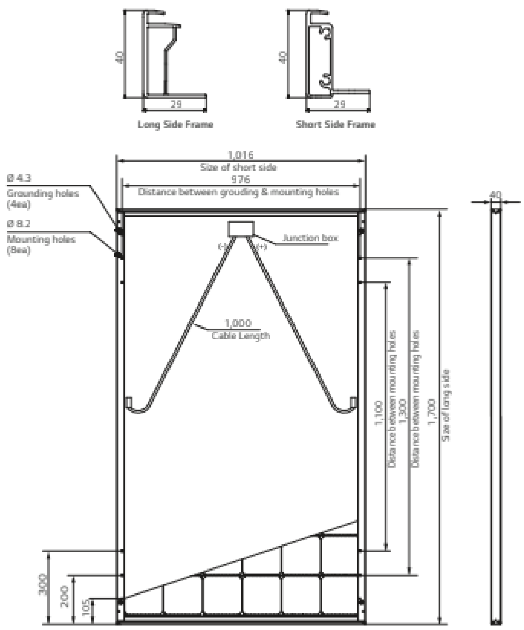
Temperature Characteristics

NOCT	[°C]	44 ± 3
Pmax	[%/°C]	-0.30
Voc	[%/°C]	-0.24
Isc	[%/°C]	0.04

Characteristic Curves



Dimensions (mm)



The distance between the center of the mounting/grounding holes.

A.3. Analysis current building

Water	Energy	Others
	The shop	
	Lights	Clothing for sale
	1 Computer	
	2 Music speakers	
	Pizza bakery	
Water tap	1 Electrical pizza oven	pizza box storage
	1 Radio	kitchen equipment
	1 Dough machine	
	1 Ventilator	
	2 Horizontal fridges	
	Lights	
	1 Extractor	
	1 Printer	
	3 Phone chargers	
	Storage room	
	Lights	Storable food
		Kitchen equipment
	Back house	
1 Water machine	3 large fridges	Storage of barrels
1 Washing machine	1 Cold room	
	1 Water machine	
	1 Water pump	
	1 Washing machine	
	2 Freezers	
	Office	
	1 Large fridge	Liquor storage
	1 Computer	Administration
	1 Ventilator	
	2 Printers	
	Lights	
	Gypsy wagen	
1 Water machine	1 Computer	Tables
	2 Printers	Chairs
	1 Horizontal fridge	Decoration
	1 Fridge	
	1 Freezer	
	1 Router	
	1 Water machine	
	Lights	

Table A.1: List of areas with associated devices sorted on Water, Energy and others. Part 1.

Water	Energy	Others
	Dishwasing area	
1 Dishwater tap	Lights	Kitchen equipment storage
1 Professional dishwasher	1 Ventilator	
1 Water heater	1 Gas water heater	
	1 Professional dishwasher	
	Kitchen	
	3 Horizontal fridges	Kitchen equipment
	1 Gas range	
	1 Electrical baking tray	
	2 Gas deep fryers	
	1 Extractor	
	1 Computer	
	1 Electrical oven	
	2 Toasters	
	Lightning	
	1 Printer	
	Bar	
1 Ice machine	Lightning	2 Beer taps
1 Water machine	2 Horizontal fridges	Liquor storage
1 Coffee machine	1 Small fridge	
	1 Wine fridge	
	1 Ice machine	
	1 Water machine	
	1 Juice machine	
	1 Coffee machine	
	1 Coffee grinder	
	2 Computers	
	2 Printers	
	3 Phone chargers	
	Public toilet and shower	
4 standard toilets	Lights	Plants
4 water taps		
1 Shower		
	Private toilet	
1 standard toilet	Lights	Employee storage
	Restaurant deck	
	Lights	Tables
		Chairs
		Decoration

Table A.2: List of areas with associated devices sorted on Water, Energy and others. Part 2.

B

Water system

B.1. Measurements of the flowrates of the devices present at Irmão

	Measurement 1			Measurement 2		
	Time [sec]	Amount [ml]	L/min	Time [sec]	Amount [ml]	L/min
Tap Kitchen	10,2	1210	7,1	8,1	1020	7,6
Tap bar	8,34	980	7,1	10,38	1180	6,8
Tap Gypsy wagon	7,84	950	7,3	8,52	1020	7,2
Tap toilet	10,1	1340	8,0	10,35	1066	6,2
Tap at the back	8,58	1030	7,2	9,6	1200	7,5
Tap employee toilet	10,43	470	2,7	10,42	490	2,8
Tap pizza area	5,23	1350	15,5	5,2	1080	12,5
Tap dishes area	4,89	650	8,0	5,3	750	8,5
Shower	5,12	1120	13,1	5,72	1280	13,4
Hoze	5,23	1380	15,8	5,06	1320	15,7

Measurement 3			Measurement 4			Measurement 5		
Time [sec]	Amount [ml]	L/min	Time [sec]	Amount [ml]	L/min	Time [sec]	Amount [ml]	L/min
7,15	910	7,6	5,52	740	8,0	6,84	830	7,3
9,88	1120	6,8	10,00	1100	6,6	10,44	1220	7,0
8,64	980	6,8	8,27	1000	7,3	7,87	930	7,1
9,56	1200	7,5	9,29	1020	6,6	11,99	1210	6,1
9,86	1210	7,4	9,99	1200	7,2	10,2	1240	7,3
9,89	470	2,9	10,86	500	2,8	10,64	510	2,9
5,25	1150	13,1	4,56	1020	13,4	4,88	1100	13,5
5,18	890	10,3	5,34	960	10,8	6,97	1040	9,0
5,05	1080	12,8	4,27	1000	14,1	4,86	1090	13,5
4,69	1200	15,4	5,29	1410	16,0	4,94	1300	15,8

Table B.1: Conducted flowrate measurements

B.2. Monthly cover and water data

	actual covers	Data monthly volume of water received from grid [m3]
January		
February	0	11
March	0	15
April	336	37
May	3392	62
June	6556	124
July	6576	96
August	8977	177
September	8572	235
October		
November		
December		

Table B.2: Monthly data obtained by the owner of Irmão. Column 2 presents the actual monitored covers of 2021 and column 3 presents the accompanying volume of water that is received from the grid in these months.

B.3. Weekly cover data and water estimation sheet

	covers weekly	Translated weekly amount of water received [m3]		Estimation covers	estimation amount of water from grid [m3]	estimation amount of water from well [m3]
week 1				374	14,7	10,8
week 2				374	14,7	10,8
week 3	0	2		374	14,7	10,9
week 4	0	2		374	14,7	11,0
week 5	0	2		0	3,3	1,1
week 6	0	2		0	3,3	1,2
week 7	0	2		0	3,3	1,3
week 8	0	4		0	3,3	1,3
week 9	0	4		213	14,0	8,7
week 10	0	4		213	14,0	8,7
week 11	0	4		213	14,0	8,8
week 12	0	3		534	15,6	14,3
week 13	0	3		534	15,6	14,4
week 14	242	18		534	15,6	14,5
week 15	94	12		534	15,6	14,6
week 16	100	9		534	15,6	14,6
week 17	257	11		687	16,6	17,3
week 18	1126	22		1430	24,4	29,9
week 19	1193	23		1430	24,4	30,0
week 20	1432	27		1494	25,3	31,1
week 21	1350	26		1557	26,2	32,3
week 22	1621	29		1621	27,1	33,4
week 23	1601	29		1601	26,8	33,2
week 24	1268	25		1581	26,5	32,9
week 25	1629	28		1560	26,2	32,7
week 26	1428	24		1540	25,9	32,4
week 27	1519	25		1519	25,6	32,1
week 28	1743	18		1743	29,0	36,0
week 29	1800	34		1800	29,9	37,0
week 30	1562	30		1981	33,0	40,2
week 31	2219	40		2163	36,4	43,3
week 32	2210	40		2344	40,0	46,4
week 33	2525	44		2525	43,9	49,3
week 34	1978	75		2288	38,9	45,2
week 35	2050	75		2050	34,3	41,2
week 36	1582	33		1782	29,6	36,6
week 37	1380	52		1680	28,0	34,8
week 38		37		1692	28,2	34,8
week 39				1647	27,5	33,9
week 40				1466	24,9	30,8
week 41				1466	24,9	30,6
week 42				1466	24,9	30,5
week 43				1466	24,9	30,4
week 44				1466	24,9	30,2
week 45				393	14,8	12,0
week 46				393	14,8	11,9
week 47				393	14,8	11,7
week 48				393	14,8	11,6
week 49				353	14,6	10,8
week 50				353	14,6	10,7
week 51				353	14,6	10,5
week 52				353	14,6	10,4

Table B.3: Data of weekly covers and monthly data translated into weekly data.

B.4. Estimation water reduction devices

Below is calculated how much water is estimated to be saved per solution per year. This is calculated as the estimated percentage saving times the annual usage of the device to be replaced.

Table B.4: Estimation water reduction devices.

Solution	**Percentage reduction**	**Annual water use [m^3]**	**Unnal water reduction [m^3]**
Sensored toilet taps with aerator	25	158	40
Water efficient shower head with pushbutton	30	116	35
Waterbroom on the hose	30	104	31
Flow regualtors on the kitchen taps	20	859	172
Vacuum toilet	30-60	768	230-460
Waterless urinals	10	768	77
Compost toilet	100	768	768
Reuse of shower and toilet water	10-20	1206	121-242

B.5. Price list water solutions

To get a good estimation of the costs of the solutions mentioned in Section 7, for each solution a product has been searched that is available for sale and are listed below. Companies were also consulted to obtain prices for certain products, the company that was consulted has been listed.

Table B.5: Price list water solutions

Option	Type	Price
Taps toilets	Bathroom automatic infrared sensor touchless water saving faucet gold	€90
Earators	Mikado low pressure tap sprout aerator	€9
Push botton	Peilgaskraan, MXT-572646370	€45
Showerhead	Lambert, model: 400004	€120
Waterbroom	Cafago waterbroom	€50
Flow regulator	Limiter shower hose seal flow restriction	€6
Pump 30 L/m	Jabsko water puppy jetpump	€175
Tank 2000 L	Tank 2000L, model: wat-bg-rond-02000	€1.000
Centrifugal pump 100 L/min	Pentair CM 100-51 230v	€240
Pump 50 L/min	W Robinson And Sons, 230 V Centrifugal Water Pump, 50L/min	€180
Compost bins	Compost system 1600 L	€175
Compost tank 1	Sunmar centrex 3000	€2.200
Compost toilet	Separet Urine diverting toilet Villa 9010	€700
Vacuum toilet	Jets Charm toilet TO611PO	€685
Waterless urinal	Urimat compact Art. 12,301	€985
Grey water tank	Grey water tank GWT 800PL	€510
Vacuum pump	Jets VU 15 MB-CTT230	€4.925
RO filter	*	€3.000

* The price is based on a phone call with Lenntech. An exact model could not be advised yet, because the water quality has to be measured first. Therefore, the price in the list is an estimate of the Lenntech employee.

C

Energy system

Beverage preparation 2 - Water machine 1 - Coffee grinder 1- Juice machine 1 - Coffee machine **Air extraction** 3 - Ventilators 2 - Extractor **Cooking** 2 - Toasters 1 - Electric oven 1 - Electrical baking tray 1 - Electrical pizza oven **Warewashing** 1 - Washing machine 1 - Professional dishwasher	**Media** 1 - Radio 6 - Phone chargers 1 - Router 6 - Computer 8 - Receip printer 8 - Speakers **Lightning** 12 - Areas with 5 lights 2 - Led Night lightning **Refrigiration** 3 - Freezer 8 - Standard Fridges 1 - Ice machine 4 - Large fridges 1 - Cold room

Table C.1: Electrical devices per category

Day	Date	Time	kWh group 1	kWh group 2	kWh group 3	kWh combined	kWh Interval	kWh Week	Covers Interval	Covers Week
Mon	*6-sep*	x	14247	12213	31890	58350				
Tue	*7-sep*									
Wed	*8-sep*									
Thu	*9-sep*									
Fri	*10-sep*									
Sat	*11-sep*									
Sun	*12-sep*						2051	2051	1782	1782
Mon	*13-sep*	x	14734	12657	33010	60401				
Tue	*14-sep*						386			
Wed	*15-sep*	x	14837	12728	33222	60787				
Thu	*16-sep*									
Fri	*17-sep*									
Sat	*18-sep*						1205			
Sun	*19-sep*	x	15128	12999	33865	61992	260	1851	1670	1670
Mon	*20-sep*									
Tue	*21-sep*									
Wed	*22-sep*						1038			
Thu	*23-sep*	12:00	15384	13225	34421	63030	281			
Fri	*24-sep*	14:00	15438	13305	34568	63311				
Sat	*25-sep*									
Sun	*26-sep*						818	2137	1692	1692
Mon	*27-sep*	13:00	15621	13493	35015	64129	124		10	
Tue	*28-sep*	11:10	15667	13508	35078	64253	255		99	
Wed	*29-sep*	11:15	15719	13567	35222	64508	349		79	
Thu	*30-sep*	14:00	15789	13657	35411	64857	236		78	
Fri	*1-okt*	11:15	15845	13693	35555	65093	486		84	
Sat	*2-okt*	16:45	15900	13876	35803	65579	115		116	
Sun	*3-okt*	11:55	15972	13831	35891	65694	263	1828	129	595
Mon	*4-okt*	12:05	16057	13876	36024	65957	169		10	
Tue	*5-okt*	13:10	16101	13923	36102	66126	244		95	
Wed	*6-okt*	11:25	16153	13958	36259	66370				
Thu	*7-okt*						570			
Fri	*8-okt*	12:15	16267	14097	36576	66940			231	
Sat	*9-okt*									
Sun	*10-okt*							983		336

Table C.2: All measured electricity levels during the interval of 6 September till 10 October

		Power				
Category	Device	Maximum Power (W	Numver of devices	Total maximum	% of max power	Real power (W)
Media	1 - Radio	3	1	3	0,8	2,4
Lightning	12 - Areas with 5 lights	15	60	900	1	900
Media	6 - Phone chargers	18	6	108	0,8	86,4
Media	1 - Router	22,5	1	22,5	0,8	18
Lightning	2 - Led Night lightning	50	2	100	1	100
Media	6 - Computer	80	6	480	0,8	384
Refrigiration	3 - Freezer	100	3	300	0,8	240
Media	8 - Receip printer	100	8	800	0,8	640
Refrigiration	8 - Standard Fridges	110	8	880	0,8	704
Beverage preparation	2 - Water machine	120	2	240	0,8	192
Beverage preparation	1 - Coffee grinder	150	1	150	0,8	120
Air extraction	3 - Ventilators	150	3	450	0,8	360
Refrigiration	1 - Ice machine	200	1	200	0,8	160
Refrigiration	4 - Large fridges	300	4	1200	0,8	960
Media	8 - Speakers	300	8	2400	0,8	1920
Beverage preparation	1- Juice machine	350	1	350	0,8	280
Cooking	1 - Dough machine	370	1	370	0,8	296
Air extraction	2 - Extractor	450	2	900	0,77	693
Water system	1 - Water pump	750	1	750	0,8	600
Cooking	2 - Toasters	1800	2	3600	0,8	2880
Cooking	1 - Electric oven	2200	1	2200	0,8	1760
Refrigiration	1 - Cold room	2346	1	2346	0,8	1876,8
Beverage preparation	1 - Coffee machine	2500	1	2500	0,8	2000
Warewashing	1 - Washing machine	2500	1	2500	0,8	2000
Warewashing	1 - Professional dishwashe	6520	1	6520	0,8	5216
Cooking	1 - Electrical baking tray	15000	1	15000	0,85	12750
Cooking	1 - Electrical pizza oven	15600	1	15600	0,97	15132
	Total	**52104,5**	**128**	**60869,5**		**52270,60**

Figure C.1: Part 1 of the *Electrical device model*. Part 1 consists of the power specifications of the devices.

Electricity consumption

Full day (Hours/day)	Full day (kWh/day	Total Full day (kW	Monday (Hours/d	Monday (kWh/day)	Total Monday (kWh/	Fully closed (Hours/	Fully closed (kWh/day)	Total fully closed (kW	Total kWh/year
8	0,0192	5,2416	4	0,0096	0,50	0	0,00	0,00	5,74
12	10,8	2948,4	6	5,4	280,80	0	0,00	0,00	3229,20
1	0,0864	23,5872	2	0,1728	8,99	0	0,00	0,00	32,57
24	0,432	117,936	24	0,432	22,46	0	0,00	0,00	140,40
8	0,8	218,4	8	0,8	41,60	8	0,80	32,00	292,00
10	3,84	1048,32	2	0,768	39,94	0	0,00	0,00	1088,26
24	5,76	1572,48	24	5,76	299,52	0	0,00	0,00	1872,00
0,25	0,16	43,68	0	0	0,00	0	0,00	0,00	43,68
24	16,896	4612,608	24	16,896	878,59	0	0,00	0,00	5491,20
8	1,536	419,328	8	1,536	79,87	0	0,00	0,00	499,20
0,5	0,06	16,38	0,25	0,03	1,56	0	0,00	0,00	17,94
8	2,88	786,24	4	1,44	74,88	0	0,00	0,00	861,12
6	0,96	262,08	6	0,96	49,92	0	0,00	0,00	312,00
24	23,04	6289,92	24	23,04	1198,08	0	0,00	0,00	7488,00
10	19,2	5241,6	8	15,36	798,72	0	0,00	0,00	6040,32
1	0,28	76,44	0	0	0,00	0	0,00	0,00	76,44
2	0,592	161,616	0	0	0,00	0	0,00	0,00	161,62
8	5,544	1513,512	2	1,386	72,07	0	0,00	0,00	1585,58
4	2,4	655,2	2	1,2	62,40	0	0,00	0,00	717,60
0,25	0,72	196,56	0	0	0,00	0	0,00	0,00	196,56
4	7,04	1921,92	0	0	0,00	0	0,00	0,00	1921,92
24	45,0432	12296,7936	24	45,0432	2342,25	0	0,00	0,00	14639,04
1	2	546	0,5	1	52,00	0	0,00	0,00	598,00
4	8	2184	2	4	208,00	0	0,00	0,00	2392,00
4	20,864	5695,872	2	10,432	542,46	0	0,00	0,00	6238,34
4	51	13923	0	0	0,00	0	0,00	0,00	13923,00
5	75,66	20655,18	0	0	0,00	0	0,00	0,00	20655,18
229	**305,61**	**83432,29**	**176,75**	**135,67**	**7054,61**	**8**	**0,80**	**32,00**	**90518,91**

Figure C.2: Part 2 of the *Electrical device model*, which consists of the electricity consumption per electrical device.

To table of contents

Electricity bill

Vazio (kWh)	Price Vazio (euro,	Ponta (kWh)	Price Ponta (eu	Cheias (kWh)	Price Cheias (	Euro/year	Device2	Category
1,36	€ 0,11	1,23	€ 0,35	3,15	€ 0,46	€ 0,92	1 - Radio	Media
699,05	€ 55,36	690,11	€ 199,44	1773,47	€ 259,10	€ 513,91	12 - Areas with 5 lights	Lightning
5,59	€ 0,44	6,96	€ 2,01	17,89	€ 2,61	€ 5,07	6 - Phone chargers	Media
27,96	€ 2,21	30,00	€ 8,67	77,11	€ 11,27	€ 22,15	1 - Router	Media
51,78	€ 4,10	62,40	€ 18,03	160,37	€ 23,43	€ 45,56	2 - Led Night lightning	Lightning
248,55	€ 19,69	232,57	€ 67,21	597,67	€ 87,32	€ 174,22	6 - Computer	Media
372,83	€ 29,53	400,06	€ 115,62	1028,10	€ 150,21	€ 295,35	3 - Freezer	Refrigiration
10,36	€ 0,82	9,33	€ 2,70	23,99	€ 3,50	€ 7,02	8 - Receip printer	Media
1093,62	€ 86,61	1173,51	€ 339,15	3015,75	€ 440,60	€ 866,36	8 - Standard Fridges	Refrigiration
99,42	€ 7,87	106,68	€ 30,83	274,16	€ 40,05	€ 78,76	2 - Water machine	Beverage preparation
3,88	€ 0,31	3,83	€ 1,11	9,85	€ 1,44	€ 2,86	1 - Coffee grinder	Beverage preparation
186,41	€ 14,76	184,03	€ 53,18	472,93	€ 69,09	€ 137,04	3 - Ventilators	Air extraction
62,14	€ 4,92	66,68	€ 19,27	171,35	€ 25,03	€ 49,23	1 - Ice machine	Refrigiration
1491,30	€ 118,11	1600,25	€ 462,47	4112,39	€ 600,82	€ 1.181,40	4 - Large fridges	Refrigiration
1242,75	€ 98,43	1290,87	€ 373,06	3317,33	€ 484,66	€ 956,15	8 - Speakers	Media
18,12	€ 1,44	16,34	€ 4,72	41,98	€ 6,13	€ 12,29	1- Juice machine	Beverage preparation
38,32	€ 3,03	34,54	€ 9,98	88,76	€ 12,97	€ 25,98	1 - Dough machine	Cooking
358,84	€ 28,42	338,85	€ 97,93	870,80	€ 127,22	€ 253,57	2 - Extractor	Air extraction
155,34	€ 12,30	153,36	€ 44,32	394,10	€ 57,58	€ 114,20	1 - Water pump	Water system
46,60	€ 3,69	42,01	€ 12,14	107,95	€ 15,77	€ 31,60	2 - Toasters	Cooking
455,68	€ 36,09	410,73	€ 118,70	1055,51	€ 154,21	€ 309,00	1 - Electric oven	Cooking
2915,50	€ 230,91	3128,48	€ 904,13	8039,73	€ 1.174,60	€ 2.309,64	1 - Cold room	Refrigiration
129,45	€ 10,25	127,80	€ 36,93	328,42	€ 47,98	€ 95,17	1 - Coffee machine	Beverage preparation
517,81	€ 41,01	511,19	€ 147,73	1313,68	€ 191,93	€ 380,67	1 - Washing machine	Warewashing
1350,46	€ 106,96	1333,18	€ 385,29	3426,08	€ 500,55	€ 992,80	1 - Professional dishwasher	Warewashing
3301,06	€ 261,44	2975,46	€ 859,91	7646,48	€ 1.117,15	€ 2.238,50	1 - Electrical baking tray	Cooking
4897,22	€ 387,86	4414,18	€ 1.275,70	11343,78	€ 1.657,33	€ 3.320,88	1 - Electrical pizza oven	Cooking
19781,43	**€ 1.566,69**	**19344,63**	**€ 5.590,60**	**49712,77**	**€ 7.263,04**	**€ 14.420,32**	**Total**	

Figure C.3: Part 3 of the *Electrical device model*. Part 3 consists of the electricity cost of Irmao.

TECHNICAL DATA FRONIUS SYMO (10.0-3-M, 12.5-3-M, 15.0-3-M, 17.5-3-M, 20.0-3-M)

INPUT DATA	SYMO 10.0-3-M	SYMO 12.5-3-M	SYMO 15.0-3-M	SYMO 17.5-3-M	SYMO 20.0-3-M
Number MPP trackers			2		
Max. input current ($I_{dc\ max\ 1}$ / $I_{dc\ max\ 2}$)	27.0 A / 16.5 A [1]		33.0 A / 27.0 A		
Max. usable input current total ($I_{dc\ max\ 1}$ + $I_{dc\ max\ 2}$)	43.5 A		51.0 A		
Max. array short circuit current (MPP_1/MPP_2)	40.5 A / 24.8 A		49.5 A / 40.5 A		
DC input voltage range ($U_{dc\ min}$ - $U_{dc\ max}$)			200 - 1000 V		
Feed-in start voltage ($U_{dc\ start}$)			200 V		
Usable MPP voltage range			200 - 800 V		
Number of DC connections			3+3		
Max. PV generator output ($P_{dc\ max}$)	15.0 kW_{peak}	18.8 kW_{peak}	22.5 kW_{peak}	26.3 kW_{peak}	30.0 kW_{peak}

OUTPUT DATA	SYMO 10.0-3-M	SYMO 12.5-3-M	SYMO 15.0-3-M	SYMO 17.5-3-M	SYMO 20.0-3-M
AC nominal output ($P_{ac,r}$)	10,000 W	12,500 W	15,000 W	17,500 W	20,000 W
Max. output power / max. rated apparent power	10,000 VA	12,500 VA	15,000 VA	17,500 VA	20,000 VA
AC output current ($I_{ac\ nom}$)	14.4 A	18.0 A	21.7 A	25.3 A	28.9 A
Grid connection (voltage range)			3-NPE 400 V / 230 V or 3~NPE 380 V / 220 V (+20 % / -30 %)		
Frequency (Frequency range)			50 Hz / 60 Hz (45 - 65 Hz)		
Total harmonic distortion	1.8 %	2.0 %	1.5 %	1.5 %	1.3 %
Power factor (cos $\phi_{ac,r}$)			0 - 1 ind. / cap.		

Figure C.4: Fronius Symo data sheet.

Roof Frontside	
Total solar panels	24,00
MPP voltage (V)	37,00
MPP current (max current) (A)	10,82
Required voltage (V)	230,00
Panels in serie	12,00
Panels parralel	2,00
Solar panel strings	2x13
Output voltage string (V)	444,00
Output current string (A)	10,82
Output voltage roof (V)	444,00
Total output current roof (A)	21,64
Max power output (Wp)	4804,08
Total max power output (Wp)	9608,16
Fronius symo 12.5-3-M	
Max input 1 current inverter (A)	27,00
Max input 2 current inverter (A)	16,50
Max input voltage inverter (V)	1000,00
Min input voltage inverter (V)	200,00
Max input power inverter (Wattp)	18800,00
Number of Inverters	1

Roof Backside	
Total solar panels	38,00
MPP voltage (V)	37,00
MPP current (max current) (A)	10,82
Required voltage (V)	230,00
Panels in serie	19,00
Panels parralel	2,00
Solar panel strings	2x13
Output voltage string (V)	703,00
Output current string (A)	10,82
Output voltage roof (V)	703,00
Total output current roof (A)	21,64
Max power output (Wp)	7606,46
Total max power output (Wp)	15212,92
Fronius symo 15.0-3-M	
Max input 1 current inverter (A)	33,00
Max input 2 current inverter (A)	27,00
Max input voltage inverter (V)	1000,00
Min input voltage inverter (V)	200,00
Max input power inverter (Wattp)	22500,00
Number of Inverters	1

Solar path 1	
Total solar panels	75,00
MPP voltage (V)	37,00
MPP current (max current)	10,82
Required voltage (V)	230,00
Panels in serie	19,00
Panels parralel	4,00
Solar panel strings	19-19
	19-18
Output voltage string: 19 (V)	703,00
Output voltage string: 18 (V)	666
Output current string (A)	10,82
Output voltage roof (V)	703,00
Total max output current Solar path 1 (A)	43,28
Max power output one string (Wp)	7606,46
Total max power output (Wp)	30025,5
Fronius symo 15.0-3-M	
Max input 1 current inverter (A)	33,00
Max input 2 current inverter (A)	27,00
Max input voltage inverter (V)	1000,00
Min input voltage inverter (V)	200,00
Max input power inverter (Wattp)	22500,00
Number of Inverters	2

Solar path 2	
Total solar panels	33,00
MPP voltage	37,00
MPP current (max current)	10,82
Required voltage (V)	230,00
Panels in serie	17,00
Panels parralel	2,00
Solar panel strings	17-16
Output voltage string: 17 (V)	629,00
Output voltage string: 16 (V)	592
Output current string (A)	10,82
Output voltage roof (V)	629,00
Total max output current Solar path 1 (A)	21,64
Max power output one string (Wp)	6805,78
Total max power output (Wp)	13211,22
Fronius symo 15.0-3-M	
Max input 1 current inverter (A)	33,00
Max input 2 current inverter (A)	27,00
Max input voltage inverter (V)	1000,00
Min input voltage inverter (V)	200,00
Max input power inverter (Wattp)	22500,00
Number of Inverters	1

Figure C.5: Inverter selection PV systems Irmão.

Cost PV system Roof				
Component	Number of devices	Cost per device	Total cost	
LG Neon R	62	€ 278,00	€	17.236,00
PVT panels Volthera (price in gas eq included)	8	€ -278,00	€	-2.224,00
DC/AC Inverter Front side	1	€ 1.949,00	€	1.949,00
DC/AC Inverter Backside	1	€ 1.979,00	€	1.979,00
AC cables 1 meter (6mm^2)	60	€ 1,056	€	63,36
DC cables 1 meter (6mm^2)	160	€ 1,056	€	168,96
Roof mounting system (per solar panel	54	€ 40,00	€	2.160,00
Total			€	21.332,32

Cost PV system Walking path 1				
Component	Number of devices	Cost per device	Total cost	
Solar panels	75	€ 278,00	€	20.850,00
DC/AC Inverter	2	€ 1.979,00	€	3.958,00
AC cables 1 m	60	€ 1,79	€	107,52
DC cables 1 m	292	€ 1,79	€	523,26
Mounting system	75	€ 40,00	€	3.000,00
Wooden construction	-	-	€	2.664,91
Total			€	31.103,70

Cost PV system Walking path 2				
Component	Number of devices	Cost per device	Total cost	
Solar panels	33	€ 278,00	€	9.174,00
DC/AC Inverter	1	€ 1.979,00	€	1.979,00
AC cables 1 m	30	€ 1,79	€	53,76
DC cables 1 m	274	€ 1,79	€	491,01
Mounting system	33	€ 40,00	€	1.320,00
Wooden construction	-	-	€	1.172,45
Total			€	14.190,22

Figure C.6: Cost overview PV systems Irmão.

Investment cost Future Irmão Energy system		
Material cost		
PV Roof	€	21.332,32
PV Solar Path 1	€	31.103,70
PV Solar Path 2	€	14.190,22
Alternatives gas devices	€	18.895,98
Labour cost		
PV Roof + PV Path 1 + PV Path 2	€	29.970,00
Consturction cost solar path	€	10.000,00
Total	€	125.492,21

Investment cost Improved Irmão Energy system		
Material cost		
PV Roof	€	21.332,32
Alternatives gas devices	€	15.000,00
Labour cost		
PV Roof	€	9.990,00
Total	€	46.322,32

Figure C.7: Investment cost Improved Irmão Energy System and Future Irmão Energy System.

D
Waste Analysis

Waste	Plastic	Paper	Glass	Rest
Monday	0	0	0	4
Tuesday	2	5	3	24
Wednesday	4	3	2	18
Thursday	3	4	3	17
Friday	3	5	2	21
Saturday	5	7	4	28
Sunday	4	8	5	31
Monday	0	0	0	3
Tuesday	2	4	2	22
Wednesday	3	3	4	6
Thursday	2	3	3	19
Friday	4	6	3	21
Saturday	6	9	5	29
Sunday	5	7	4	28
Avg per day (w/ mondays)	**3.1**	**4.6**	**2.9**	**19.4**

Table D.1: Measurement amount of waste at Irmão

E

Matlab code

E.1. Meteonorm data visualisation

```
% Visualize data from Meteonorm
% MDP Irmao
% 21−08−2021

TotalIrmao = readmatrix('Irmao2020');
MonthsYear = 1:12;
WeeksYear = 1:52;
DaysYear = 1:365;
HoursYear = 1:8760;
x = HoursYear;

%% Individual parameters
Temp = TotalIrmao(:,11); %temperature in degrees
WindSpeed = TotalIrmao(:,32); %windspeeds
SunHeight = TotalIrmao(:,12); %Height of the sun
Percipation = TotalIrmao(:,35); %Percipation in mm
Irradiance = TotalIrmao(:,6); %Irradiance
SunHours = TotalIrmao(:,29); %Sun hours per hour
WindDirection = −TotalIrmao(:,33); %Direction in degrees
WindDirectionFixed = WindDirection./57.2958; %Degrees to radians

%% Temperature at 2 meter above ground
for i = 1:365
    TempDayTot(i) = sum(Temp(1+24∗(i−1):24∗(i)));
    TempDayAvg(i) = TempDayTot(i)/24 ;
end

for i = 1:52
    TempWeekTot(i) = sum(Temp(1+7∗(i−1):7∗(i)));
    TempWeekAvg(i) = TempWeekTot(i)/7 ;
end

figure(1)
plot(DaysYear,TempDayAvg,'color',[0 0.6 0.5],'LineWidth',1.5)
title('Temperature at Irmão from Meteonorm')
xlim([0 365])
ylim([0 30])
xticks([15.2083 15.2083+1∗365/12 15.2083+2∗365/12 15.2083+3∗365/12 15.2083+4∗365/12 ...
    15.2083+5∗365/12 15.2083+6∗365/12 15.2083+7∗365/12 15.2083+8∗365/12 ...
    15.2083+9∗365/12 15.2083+10∗365/12 15.2083+11∗365/12 15.2083+12∗365/12 ])
xticklabels({'Jan','Feb','Mar','Apr','May','Jun','Jul','Aug','Sep','Okt','Nov','Dec'})
ylabel('Temperature [∗C]');
xlabel('Month');

%% Total irradiance
for i = 1:365
    IrradianceDaySum(i) = sum(Irradiance(1+24∗(i−1):24∗(i)));
```

```
end

for i = 1:52
    IrradianceWeekSum(i) = sum(IrradianceDaySum(1+7*(i-1):7*(i)))./1000;
end
x = linspace(1,52);
FitIrradiance = (0.109149552968920*x.^4 -11.3687165287747*x.^3 + 314.807243953017 *x.^2 ...
    -1027.70825265134*x + 15847.2904007755)./1000;

figure(2)
bar(WeeksYear,IrradianceWeekSum)
hold on
plot(x,FitIrradiance)
title('Solar radiation per week at Irmão from Meteonorm')
xlim([0 52])
xlabel('Week')
ylabel('Solar radiation [kWh/m^2]')
legend('Meteonorm', '5th order polynom')

TotalIrradiance = sum(Irradiance);

%% Sun height
for i = 1:365
    MaxSunHeight(i) = max(SunHeight(1+24*(i-1):24*(i)));
end

figure(3)
plot(DaysYear,MaxSunHeight)
xlim([0 365])
ylim([0 90])
title('Sun height at Irmão from Meteonorm')
ylabel('Maximum sun height [degrees]');
xlabel('Day');

MaxHeightYear = max(MaxSunHeight)
MinHeightYear = min(MaxSunHeight)

%% Sunhours per day
for i = 1:365
    SunHoursDaySum(i) = sum(SunHours(1+24*(i-1):24*(i)))/60;
end
for i = 1:52
    SunHoursWeekSumAvg(i) = sum(SunHoursDaySum(1+7*(i-1):7*(i)))/7;
end

x = WeeksYear;
ESH = 4.98057735059620e-07*x.^5 - 4.47905153420282e-05*x.^4 + 0.000785127878863951*x.^3 ...
    + 0.0102074956886975*x.^2  + 0.0110672550754574*x + 4.55596494407919 %estimater


figure(4)
bar(WeeksYear,SunHoursWeekSumAvg)
hold on
plot(x,ESH)
title('Average sun hours per day at Irmão from Meteonorm')
xlim([0 52])
xlabel('Week')
ylabel('Sunhours per day [h]')
hold off
legend('Meteonorm','5th order Fit')


%% Precipitation
for i = 1:365
    PercipationDaySum(i) = sum(Percipation(1+24*(i-1):24*(i)));
end

for i = 1:52
    PercipationWeekSum(i) = sum(PercipationDaySum(1+7*(i-1):7*(i)));
end

```

```
PercipationMonthJan = sum(PercipationDaySum(1:31));
PercipationMonthFeb = sum(PercipationDaySum(32:59));
PercipationMonthMar = sum(PercipationDaySum(60:90));
PercipationMonthApr = sum(PercipationDaySum(91:120));
PercipationMonthMay = sum(PercipationDaySum(121:151));
PercipationMonthJun = sum(PercipationDaySum(152:181));
PercipationMonthJul = sum(PercipationDaySum(182:212));
PercipationMonthAug = sum(PercipationDaySum(213:243));
PercipationMonthSep = sum(PercipationDaySum(244:273));
PercipationMonthOkt = sum(PercipationDaySum(274:304));
PercipationMonthNov = sum(PercipationDaySum(305:334));
PercipationMonthDec = sum(PercipationDaySum(334:365));

MonthlyPercipation = [PercipationMonthJan, PercipationMonthFeb, PercipationMonthMar, ...
    PercipationMonthApr, PercipationMonthMay, PercipationMonthJun, PercipationMonthJul, ...
    PercipationMonthAug, PercipationMonthSep, PercipationMonthOkt, PercipationMonthNov, ...
    PercipationMonthDec];
figure(5)
bar(MonthsYear, MonthlyPercipation)
title('Precipitation at Irmão from Meteonorm')
ylabel('Percipitation [mm]')
xticks([1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12])
xticklabels({'Jan','Feb','Mar','Apr','May','Jun','Jul','Aug','Sep','Okt','Nov','Dec'})
xlabel('Month')

%% Wind box
WSJan = WindSpeed(1:730);
WSFeb = WindSpeed(731:1460);
WSMar = WindSpeed(1461:2190);
WSApr = WindSpeed(2191:2920);
WSMay = WindSpeed(2921:3650);
WSJun = WindSpeed(3651:4380);
WSJul = WindSpeed(4381:5110);
WSAug = WindSpeed(5111:5840);
WSSep = WindSpeed(5841:6570);
WSOkt = WindSpeed(6571:7300);
WSNov = WindSpeed(7301:8030);
WSDec = WindSpeed(8031:8760);

WSYear = [WSJan,WSFeb,WSMar,WSApr,WSMay,WSJun,WSJul,WSAug,WSSep,WSOkt,WSNov,WSDec];
figure(6)
boxplot(WSYear)
ylabel('Windspeed [m/s]')
xlabel('Month')
xticks([1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12])
xticklabels({'Jan','Feb','Mar','Apr','May','Jun','Jul','Aug','Sep','Okt','Nov','Dec'})
title('Monthly wind speed at Irmão from Meteonorm')

%% Wind Turbine generation
RatedPower = 3;     %kW
Vrated = 10;        %rated wind speed m/s
Vin = 3.0;          %cut in wind speed m/s
Vout = 25;        %cut out wind speed m/s

Bin = [2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 ];
PPB = [0 110 210 400 720 1100 1650 2300 2900 3000 3000 3000 3000 3000 3000 3000 3000 ...
    3000 3000 3000 3000 3000 3000 3000 3000 3000]; %power per bin

V = WindSpeed;
B(1) = sum( V ≤ Vin & V ≤ 2); %Below Vin
B(2) = sum(V > Vin & V ≤ 3.5);
B(3) = sum(V > 3.5 & V ≤ 4.5);
B(4) = sum(V > 4.5 & V ≤ 5.5);
B(5) = sum(V > 5.5 & V ≤ 6.5);
B(6) = sum(V > 6.5 & V ≤ 7.5);
B(7) = sum(V > 7.5 & V ≤ 8.5);
B(8) = sum(V > 8.5 & V ≤ 9.5);
B(9) = sum(V > 9.5 & V ≤ Vrated); % In full capacity region
B(10) = sum(V > Vrated & V ≤ Vout);% Above V cut-out
topspeed = max(V);
```

```
for i = 1:10
    TotalPower = sum(PPB(i)*B(i)) % total energy generated per year in Wh
end

%% wind speed max wind week avg
for i = 1:52
    MaxWindspeedWeek(i) = max(WindSpeed(1+168*(i-1):168*(i)));
    ErrorPosW(i) = MaxWindspeedWeek(i) - WindSpeedWeekAvg(i);
end

for i = 1:52
    MinWindspeedWeek(i) = min(WindSpeed(1+168*(i-1):168*(i)));
    ErrorNegW(i) =  WindSpeedWeekAvg(i) - MinWindspeedWeek(i);
end

figure(8)
errorbar(WeeksYear,WindSpeedWeekAvg,ErrorNegW,ErrorPosW)
xlim([0 52])
ylabel('Averaged windspeed in m/s');
xlabel('Weeks of the year');
title('Weekly average windspeed')
```

E.2. PV system

```
% PV system Irmao
% Made for MDP
% excelfile: Irmao2020 required
% 29-08-2021

%% Location of Irmao
clc
clear all

UTC = 0;
latitude = 38.61;
longitude = -9.14;
altitude = 11;
Bifacefactor= 0.0941;
HoursYear = linspace(1,8760,8760);
DaysYear = linspace(1,365,365);
WeeksYear = linspace(1,52,52);
%% Roof characteristics and orientation
SSRoof_W = 9.5;  % length of the seaside roof parallel to the beach
SSRoof_L = 5.1;  % length of the seaside roof normal to the beach
BSRoof1_W = 4.5; % length of the seaside1 roof normal to the beach
BSRoof1_L = 7.1; % length of the seaside1 roof parallel to the beach
BSRoof2_W = 5.0; % length of the seaside2 roof normal to the beach
BSRoof2_L = 6.0; % length of the seaside2 roof parallel to the beach

SeasideTilt = 13;   % degrees
BacksideTilt = 13;  % degrees

SeasideAzimuth = 240; % degrees
BacksideAzimuth = 80; % degrees
Albedo = 0.35;           %albedo at the beach

%% Data extraction
EXC = readmatrix('Irmao2020');
GHI = EXC(:,6);                  % GHI
DNI = EXC(:,10);                 % DNI
DHI = EXC(:,7);                  % DHI
Solar_azimuth = EXC(:,13);       % solar azimuth
Wspeed = EXC(:,32);              % wind speed
Ta = EXC(:,11);                  % ambient temp
Tground = EXC(:,31);             % ground temp
N = EXC(:,36);                   % cloud coverage
SunHeight = EXC(:,12);           % sun height
Ts = EXC(:,31);                  % ground temp
```

```
Tsky = EXC(:,14);             % sky temp
EnergyIncident = trapz(GHI)*10^-3; % Irradiation on location in kWh / m^2

% Calculate solar altitude
Location = pvl_makelocationstruct(latitude,longitude,altitude);
DN = datenum(2005,1,1):1/(24):datenum(2005, 12, 31, 23, 59, 59);
Time = pvl_maketimestruct(DN, UTC);
[SunAz2, SunEl, ApparentSunEl, SolarTime]=pvl_ephemeris(Time,Location);
SunEl2 = max(SunEl,0);

%% Optimal module orientation calculation

%Precalculation definitions and allocations
SunAz = Solar_azimuth + 180;
Tilt_angle = linspace(0,90,91);
DOY = linspace(1,365,365);
SunZen = 90 - SunEl2;
Hextradaily = pvl_extraradiation(DOY);
Hextra = repelem(Hextradaily,24)';
Am = linspace(0,359,360);
Irradiance = zeros(91,360);

for i = 1:91
    for j = 1:360
        SurfTilt = repelem(Tilt_angle(i),8760)';
        SurfAz = repelem(Am(j),8760)';
        SkyDiffuse = pvl_reindl1990(SurfTilt, SurfAz, DHI, DNI, GHI, Hextra, SunZen, ...
            SunAz);
        GR = pvl_grounddiffuse(SurfTilt,GHI,Albedo);
        AOI = pvl_getaoi(SurfTilt,SurfAz,SunZen,SunAz);
        DR = DNI.*cos(AOI.*(pi/180));
        TotalIR = DR + SkyDiffuse + GR;
        Irradiance(i,j) = sum(TotalIR(:));
    end
end

% Calculate and plot optimum solutions
[X,Y] = meshgrid(Am,Tilt_angle);
IR = Irradiance*10^-3;

%% Plotting the tilt vs azimuth irradiance
figure(1)
contourf(X,Y,IR,'ShowText','on')
title('Solar Irradiation at Irmão [kWh/m^{2}/year]','FontSize',12)
ylabel('Module Tilt [degrees]')
xlabel('Module Azimuth [degrees]')

%% Optimum angle of tilt and azimuth
maxIR=max(IR(:));
[MaxTilt,MaxAzimuth]= find(IR==maxIR);

% optimal tilt given that Azimuth stays at 240 (Azimuth Irmao)
MaxIRFixedAzimuth = max(IR(:,SeasideAzimuth));
[MaxTiltFixedAzimuth,SeasideAzimuth]= find(IR==MaxIRFixedAzimuth);


%% Parameters of the PV panels and choosing right panel
clc

n = input(['Select a module assigning a number from 1 to 4 and press enter:'...
    newline '1.LG395N2T-A5'...
    newline '2.REC TWINPEAK 2 MONO '...
    newline '3.LG370Q1C-A5'...
    newline '4.SPR-MAX3-400'...
    newline '5.DMEGC DM325G1'...
    newline]);

while n > 5 || n < 1
n = input(['Error! Please choose an integer number between 1 and 5'...
    newline]);
end
```

```
switch n

     case 1
% LG NEON 2 BiFacial − LG395N2T−A5
Panel_W = 2.064; %m
Panel_L = 1.024; %m
EffPanel = 0.187; %efficiency of panel
PanelPrice = 345; %eu per panel

     case 2
% REC TWINPEAK 2 MONO − Best option
Panel_W = 1.675; %m
Panel_L = 0.997 %m
EffPanel = 0.198; %efficiency of panel
PanelPrice = 167,42; %eu per panel

     case 3
% LG370Q1C−A5
Panel_W = 1.7; %m
Panel_L = 1.016; %m
EffPanel = 0.214; %efficiency of panel
PanelPrice = 278; %eu per panel

     case 4
% SPR−MAX3−400
Panel_W = 1.69; %m
Panel_L = 1.046; %m
EffPanel = 0.226; %efficiency of panel
PanelPrice = 334; %eu per panel

     case 5
% DMEGC DM325G1−60BB
Panel_W = 1.665; %m
Panel_L = 1.002; %m
EffPanel = 0.195; %efficiency of panel
PanelPrice = 127; %eu per panel
end

% Configuration of the panels
oppPanel = Panel_W*Panel_L; % opp panel in m^2

clc
% Modules configuration Seaside
nRowSS_Land = floor(SSRoof_W/Panel_W);
nColSS_Land = floor(SSRoof_L/Panel_L);
nTotSS_Land = nRowSS_Land*nColSS_Land;        %total panels on Seaside when in landscape
nRowSS_Port = floor(SSRoof_W/Panel_L);
nColSS_Port = floor(SSRoof_L/Panel_W);
nTotSS_Port = nRowSS_Port*nColSS_Port;        %total panels on Seaside when in portrait

if nTotSS_Land > nTotSS_Port
     nMaxSS = nTotSS_Land;
     disp(['Seaside best lay−out option is landscape with: ', num2str(nMaxSS), ', ...
          C=',num2str(nRowSS_Land), ' R=',num2str(nColSS_Land)])
else
     nMaxSS = nTotSS_Port;
     disp(['Seaside best lay−out option is portrait with: ', num2str(nMaxSS), ', ...
          C=',num2str(nRowSS_Port), ' R=',num2str(nColSS_Port)])
end
nModulesBaseSS = nMaxSS;    % total modules on the seaside roof

% Modules configuration Backside1
nRowBS1_Land = floor(BSRoof1_W/Panel_W);
nColBS1_Land = floor(BSRoof1_L/Panel_L);
nTotBS1_Land = nRowBS1_Land*nColBS1_Land;        %total panels on Backside1 when in ...
     landscape
nRowBS1_Port = floor(BSRoof1_W/Panel_L);
nColBS1_Port = floor(BSRoof1_L/Panel_W);
nTotBS1_Port = nRowBS1_Port*nColBS1_Port;        %total panels on Backside1 when in ...
     portrait
```

```matlab

if nTotBS1_Land > nTotBS1_Port
    nMaxBS1 = nTotBS1_Land;
    disp(['Backside1 best lay-out option is landscape with: ', num2str(nMaxBS1), ', ...
        C=',num2str(nRowBS1_Land), ' R=',num2str(nColBS1_Land)])
else
    nMaxBS1 = nTotBS1_Port;
    disp(['Backside1 best lay-out option is portrait with: ', num2str(nMaxBS1), ', ...
        C=',num2str(nRowBS1_Port), ' R=',num2str(nColBS1_Port)])
end

% Modules configuration Backside2
nRowBS2_Land = floor(BSRoof2_W/Panel_W);
nColBS2_Land = floor(BSRoof2_L/Panel_L);
nTotBS2_Land = nRowBS2_Land*nColBS2_Land;       %total panels on Backside2 when in ...
    landscape
nRowBS2_Port = floor(BSRoof2_W/Panel_L);
nColBS2_Port = floor(BSRoof2_L/Panel_W);
nTotBS2_Port = nRowBS2_Port*nColBS2_Port;       %total panels on Backside2 when in ...
    portrait

if nTotBS2_Land > nTotBS2_Port
    nMaxBS2 = nTotBS2_Land;
    disp(['Backside2 best lay-out option is landscape with: ', num2str(nMaxBS2), ', ...
        C=',num2str(nRowBS2_Land), ' R=',num2str(nColBS2_Land)])
else
    nMaxBS2 = nTotBS2_Port;
    disp(['Backside2 best lay-out option is portrait with: ', num2str(nMaxBS2), ', ...
        C=',num2str(nRowBS2_Port), ' R=',num2str(nColBS2_Port)])
end

nModulesBaseBS = nMaxBS1 + nMaxBS2;  % total modules on the backside roof in base ...
    scenario
nModulesPVT = 8
nModulesBaseSS = 24 - nModulesPVT;
nModulesBaseBS = 38;
nTotModulesRoofBase = nModulesBaseSS + nModulesBaseBS;% total modules on the roof in ...
    basescenario

% Total irradiance on panels Seaside Base scenario
AOI_baseSS = pvl_getaoi(SeasideTilt,SeasideAzimuth,SunZen,SunAz);  %angle of irradiance ...
    base seaside

% the different components of irradiance
SkyDiffuse_baseSS = pvl_reindl1990(SeasideTilt, SeasideAzimuth, DHI, DNI, GHI, Hextra, ...
    SunZen, SunAz);
GR_baseSS = pvl_grounddiffuse(SeasideTilt,GHI,Albedo);
DR_baseSS = DNI.*cos(AOI_baseSS.*(pi/180));

TotalIRBaseSS = DR_baseSS + SkyDiffuse_baseSS + GR_baseSS;  %total irradiance ...
    experienced by single panel at Seaside [Wh/m^2]
TotIR_Single_BaseSS = sum(TotalIRBaseSS);
HourlyPowerOutputSingleBaseSS = TotalIRBaseSS*EffPanel*oppPanel; %power output of ...
    single panel at seaside per hour [Wh]
AnnualPowerOutputSingleBaseSS = sum(HourlyPowerOutputSingleBaseSS);   %annual power ...
    output of single panel at seaside [Wh]
UTT_BaseSS = sum(HourlyPowerOutputSingleBaseSS);

disp(['Annual output of base scenario single Seaside panel: ' , ...
    num2str(AnnualPowerOutputSingleBaseSS/1000) ' kWh']);

AnnualPowerOutputTotalBaseSS = AnnualPowerOutputSingleBaseSS*nModulesBaseSS/1000000;    ...
    %total annual output of all panels combined at seaside [MWh]
disp(['Total annual output of seaside in MWh: ', num2str(AnnualPowerOutputTotalBaseSS), ...
    ' by ' num2str(nModulesBaseSS), ' panels'])

% Total irradiance on panels Backside Base scenario
AOI_baseBS = pvl_getaoi(BacksideTilt,BacksideAzimuth,SunZen,SunAz);

% the different components of irradiance
```

```
SkyDiffuse_baseBS = pvl_reindl1990(BacksideTilt,BacksideAzimuth, DHI, DNI, GHI, Hextra, ...
    SunZen, SunAz);
GR_baseBS = pvl_grounddiffuse(BacksideTilt,GHI,Albedo);
DR_baseBS = DNI.*cos(AOI_baseBS.*(pi/180));

TotalIRBaseBS = DR_baseBS + SkyDiffuse_baseBS + GR_baseBS;      %total irradiance ...
    experienced by single panel at Seaside [Wh/m^2]
HourlyPowerOutputSingleBaseBS = TotalIRBaseBS*EffPanel*oppPanel;      %power output of ...
    single panel at seaside [Wh]
AnnualPowerOutputSingleBaseBS = sum(HourlyPowerOutputSingleBaseBS);        %total ...
    annual power output of single panel at seaside [Wh/m^2]

AnnualPowerOutputTotalBaseBS = nModulesBaseBS*AnnualPowerOutputSingleBaseBS/10^6;    ...
    %total annual output of all panels combined at seaside [MWh]
disp(['Annual output of base scenario single Backside panel: ' , ...
    num2str(AnnualPowerOutputSingleBaseBS/1000) ' kWh']);
disp(['Total annual output of Backside in MWh: ', ...
    num2str(AnnualPowerOutputTotalBaseBS), ' by ' num2str(nModulesBaseBS), ' panels'])
CombinedAnnualOutputBase = AnnualPowerOutputTotalBaseSS + AnnualPowerOutputTotalBaseBS;
disp(['Total annual output of total base scenario in MWh: ...
    ',num2str(CombinedAnnualOutputBase)]) % total output of SS and BS

TotalPanelPrice = nTotModulesRoofBase*PanelPrice;
disp(['Total price of the panels: ',num2str(TotalPanelPrice),' Euro'])

EuroPerkWh = TotalPanelPrice/(CombinedAnnualOutputBase*20)/1000;
disp(['Total price per kWh: ',num2str(EuroPerkWh),' Euro/kWh at an lifetime of 20 ...
    years'])

HourlyCombinedOutput = ...
    (HourlyPowerOutputSingleBaseSS*nModulesBaseSS+HourlyPowerOutputSingleBaseBS*nModulesBaseBS)/1000; ...
    % hourly output of total installation
MaxHourlyOutputInstallation = max(HourlyCombinedOutput);

for i = 1:365
    OutputDay(i) = sum(HourlyCombinedOutput(1+24*(i-1):24*(i)));
end

%% Tilted system scenario
clc

Tilt_TS = MaxTiltFixedAzimuth;
AOI_TS = pvl_getaoi(Tilt_TS,SeasideAzimuth,SunZen,SunAz);  %angle of irradiance at ...
    maximized tilt.

% the different components of irradiance
SkyDiffuse_TS = pvl_reindl1990(Tilt_TS, SeasideAzimuth, DHI, DNI, GHI, Hextra, SunZen, ...
    SunAz);
GR_TS = pvl_grounddiffuse(Tilt_TS,GHI,Albedo);
DR_TS = DNI.*cos(AOI_TS.*(pi/180));

nModules_TS = 24;

TotalIR_TS = DR_TS + SkyDiffuse_TS + GR_TS;  %total irradiance experienced by single ...
    panel at Seaside at TS [Wh/m^2]
TotIR_Single_TS = sum(TotalIR_TS);                   %total annual irradiance at one panel
HourlyPowerOutputSingle_TS = TotalIR_TS*EffPanel*oppPanel; %power output of single ...
    panel at seaside per hour at TS [Wh]
AnnualPowerOutputSingle_TS = sum(HourlyPowerOutputSingle_TS);   %annual power output of ...
    single panel at seaside at TS [Wh]
UTT_TS = sum(HourlyPowerOutputSingle_TS);

 %total annual output of all panels combined at seaside [MWh]
disp(['Annual output of TS scenario single panel: ' , ...
    num2str(AnnualPowerOutputSingle_TS/1000) ' kWh']);
% disp(['Annual output of TS scenario seaside: ' , num2str(AnnualPowerOutputTotal_TS) ' ...
    MWh']);

InstalledPanelsTS_SS = 4*6; % installed panels at SS + upper row of BS
InstalledPanelsTS_BS = 6*3+3; % total installed on Backside without upper layer
nModules_TS = InstalledPanelsTS_SS + InstalledPanelsTS_BS; % total panels
```

```
AnnualSS_Ts = InstalledPanelsTS_SS*AnnualPowerOutputSingle_TS/10^6
AnnualBS_TS = InstalledPanelsTS_BS*AnnualPowerOutputSingle_TS/10^6
AnnualPowerOutputTotal_TS = nModules_TS*AnnualPowerOutputSingle_TS/10^6

%% Optimal Tilt and Azimuth Situation

AOI_OA = pvl_getaoi(MaxTilt,MaxAzimuth,SunZen,SunAz); %angle of irradiance at ...
    maximized tilt.

% the different components of irradiance
SkyDiffuse_OA = pvl_reindl1990(MaxTilt, MaxAzimuth, DHI, DNI, GHI, Hextra, SunZen, ...
    SunAz);
GR_OA = pvl_grounddiffuse(MaxTilt,GHI,Albedo);
DR_OA = DNI.*cos(AOI_OA.*(pi/180));

nModules_OA = 17+12;

TotalIR_OA = DR_OA + SkyDiffuse_OA + GR_OA; %total irradiance experienced by single ...
    panel at Seaside at TS [Wh/m^2]
TotIR_Single_OA = sum(TotalIR_OA);                %total annual irradiance at one panel
HourlyPowerOutputSingle_OA = TotalIR_OA*EffPanel*oppPanel; %power output of single ...
    panel at seaside per hour at TS [Wh]
AnnualPowerOutputSingle_OA = sum(HourlyPowerOutputSingle_OA);   %annual power output of ...
    single panel at seaside at TS [Wh]
UTT_OA = sum(HourlyPowerOutputSingle_OA);

AnnualPowerOutputTotal_OA = nModules_OA*AnnualPowerOutputSingle_OA/10^6   %total annual ...
    output of all panels combined at seaside [MWh]
disp(['Annual output of OA scenario single panel: ' , ...
    num2str(AnnualPowerOutputSingle_OA/1000) ' kWh']);

% for later
% disp(['Total annual output of Seaside in MWh: ', ...
    num2str(AnnualPowerOutputTotalBaseBS), ' by ' num2str(nModulesBaseBS), ' panels'])
% CombinedAnnualOutputBase = AnnualPowerOutputTotalBaseSS + AnnualPowerOutputTotalBaseBS;
% disp(['Total annual output of total base scenario in MWh: ...
    ',num2str(CombinedAnnualOutputBase)]) % total output of SS and BS

TotalPanelPrice = nModules_OA*PanelPrice;
disp(['Total price of the panels: ',num2str(TotalPanelPrice),' Euro'])

EuroPerkWh = TotalPanelPrice/CombinedAnnualOutputBase/1000;
disp(['Total price per kWh: ',num2str(EuroPerkWh),' Euro/kWh'])


%% Dual Axis system
%Precalculation definitions and allocations
SunAz = Solar_azimuth + 180;
Tilt_angle = linspace(0,90,91);
DOY = linspace(1,365,365);
SunZen = 90 - SunEl2;
Hextradaily = pvl_extraradiation(DOY);
Hextra = repelem(Hextradaily,24)';
Am = linspace(0,359,360);

for i = 1:8760
    SurfTilt = SunEl2;
    SurfAz = SunAz;
    AOI = pvl_getaoi(SurfTilt,SurfAz,SunZen,SunAz);
    SkyDiffuse = pvl_reindl1990(SurfTilt, SurfAz, DHI, DNI, GHI, Hextra, SunZen, SunAz);
    GR = pvl_grounddiffuse(SurfTilt,GHI,Albedo);
    DR = DNI.*cos(AOI.*(pi/180));
    TotalIR = DR + SkyDiffuse + GR;
    IrradianceDualAxis = sum(TotalIR)/1000; %total annual irradiance in [kWh/m^2]
end

% Presenting outcome
disp(['Annual irradiance at dual axis panel: ' , num2str(IrradianceDualAxis) ' ...
    kWh/m^2']);
TotalOutputDAPanel = IrradianceDualAxis*oppPanel*EffPanel;
```

```
disp(['Annual output at dual axis panel: ' , num2str(TotalOutputDAPanel) ' kWh']);


%% Comparison between the three different panels
disp(['Annual output of base scenario single Seaside panel: ' , ...
    num2str(AnnualPowerOutputSingleBaseSS/1000) ' kWh']);
disp(['Annual output of base scenario single Backside panel: ' , ...
    num2str(AnnualPowerOutputSingleBaseBS/1000) ' kWh']);
disp(['Annual output of TS scenario single panel: ' , ...
    num2str(AnnualPowerOutputSingle_TS/1000) ' kWh']);
disp(['Annual output of OA scenario single panel: ' , ...
    num2str(AnnualPowerOutputSingle_OA/1000) ' kWh']);
disp(['Annual output at dual axis panel: ' , num2str(TotalOutputDAPanel) ' kWh']);

%% Solar carport output
Azimuth_CP = 150;
Tilt_CP = 10.5;
AOI_CP = pvl_getaoi(Tilt_CP,Azimuth_CP,SunZen,SunAz); %angle of irradiance at ...
    maximized tilt.

% the different components of irradiance
SkyDiffuse_CP = pvl_reindl1990(Tilt_CP, Azimuth_CP, DHI, DNI, GHI, Hextra, SunZen, ...
    SunAz);
GR_CP = pvl_grounddiffuse(Tilt_CP,GHI,Albedo);
DR_CP = DNI.*cos(AOI_CP.*(pi/180));

W_Canopy1 = 33.20; %m
W_Canopy2 = 56.25; %m
W_Canopy3 = 73.07; %m
L_Canopy = 10.17; %m

nW_Canopy1 = floor(W_Canopy1/Panel_W); %amout panels per Canopy
nW_Canopy2 = floor(W_Canopy2/Panel_W);
nW_Canopy3 = floor(W_Canopy3/Panel_W);
nL_Canopy = floor(L_Canopy/Panel_L);

n_Canopy1 = nL_Canopy*nW_Canopy1;
n_Canopy2 = nL_Canopy*nW_Canopy2;
n_Canopy3 = nL_Canopy*nW_Canopy3;

nModules_CP = n_Canopy1 + n_Canopy2 + n_Canopy3;

TotalIR_CP = DR_CP + SkyDiffuse_CP + GR_CP; %total irradiance experienced by single ...
    panel at Seaside at TS [Wh/m^2]
TotIR_Single_CP = sum(TotalIR_CP);              %total annual irradiance at one panel
HourlyPowerOutputSingle_CP = TotalIR_CP*EffPanel*oppPanel; %power output of single ...
    panel at seaside per hour at TS [Wh]
AnnualPowerOutputSingle_CP = sum(HourlyPowerOutputSingle_CP);  %annual power output of ...
    single panel at seaside at TS [Wh]
UTT_CP = sum(HourlyPowerOutputSingle_CP);

disp(['Annual output of CP scenario single panel: ' , ...
    num2str(AnnualPowerOutputSingle_CP/1000) ' kWh']);

AnnualPowerOutputTotal_CP = nModules_CP*AnnualPowerOutputSingle_CP/10^6;  %total ...
    annual output of all panels combined at seaside [MWh]
disp(['Annual output of total CP: ' , num2str(AnnualPowerOutputTotal_CP) ' MWh']);
% for later
% disp(['Total annual output of Seaside in MWh: ', ...
    num2str(AnnualPowerOutputTotalBaseBS), ' by ' num2str(nModulesBaseBS), ' panels'])
% CombinedAnnualOutputBase = AnnualPowerOutputTotalBaseSS + AnnualPowerOutputTotalBaseBS;
% disp(['Total annual output of total base scenario in MWh: ...
    ',num2str(CombinedAnnualOutputBase)]) % total output of SS and BS

TotalPanelPrice = nModules_CP*PanelPrice;
disp(['Total price of the panels: ',num2str(TotalPanelPrice),' Euro'])

EuroPerkWh = TotalPanelPrice/CombinedAnnualOutputBase/10^6;
disp(['Total price per kWh: ',num2str(EuroPerkWh),' Euro/kWh'])

OutputPerHour_CP = HourlyPowerOutputSingle_CP*nModules_CP;
```

```
for i = 1:365
    OutputDay_CP(i) = sum(OutputPerHour_CP(1+24*(i-1):24*(i)));
end

%% Temperature module
% PV Module Parameters
EffPanel = 0.214; %efficiency of panel

L = 1.7; % [m]
W = 1; % [m]
Dh = 2*L*W/(L+W);
emi_front = 0.84;          % Solar Book
emi_back = 0.89;           % Solar Book
T_NOCT = 44+273;           % Normal Operating Cell Temp
T_INOCT = T_NOCT - 3;
Ref = 0.1;                 % Solar Book
alfa = (1-Ref)*(1-EffPanel); % Solar Book

%Constants
g = 9.8 ; % [m/s^2]
Pr = 0.71; % Prandlt number
kVis = 14.6e-6; % [m^2/s] air kinematic viscosity
muair = 1.837*10^-5; %[kg/ms] air dynamic viscosity
rho = 1.225; % [kg/m^3] air density
Cp = 1005; % [J/kg/K] air heat capacity
kT = 0.026; % [W/m*K] thermal conductivity of air in
Sb = 5.67*10^-8; % [W/m^2/K^4 ] Stefan-Boltzmnan constant
%NOCT conditions
Gm_NOCT = 800; %[W/m^2] Irradiance level at NOCT
w_NOCT = 1; %[m/s] Wind speed at NOCT
Ta_NOCT = 20 + 273; %[K] Ambient temperature at NOCT

Re_NOCT = w_NOCT*Dh/kVis; %NOCT Reynolds number

if Re_NOCT>1.2e5
    h_forced_NOCT = (0.86*Re_NOCT^(-0.5))*rho*Cp*w_NOCT/Pr^(0.67);%turbulent
else
    h_forced_NOCT = (0.028*Re_NOCT^(-0.2))*rho*Cp*w_NOCT/Pr^(0.4);%laminar
end

for h = 1:8760
    % Forced convection
    % Reynolds number at the specified environmental conditions
    Re(h) = Wspeed(h)*Dh/muair;

    if Wspeed(h) == 0
        h_forced(h) = 0;
    elseif Re(h)>1.2e5
        h_forced(h) = 0.86*Re(h).^(-0.5)*rho*Cp.*Wspeed(h)/Pr^(0.67);%turbulent
    else
        h_forced(h) = 0.028*Re(h).^(-0.2)*rho*Cp.*Wspeed(h)/Pr^(0.4);%laminar
    end
end
h_forced = h_forced';

%% Temperature of the module surface
Gr_NOCT = g*(1./Ta)*(T_NOCT-Ta_NOCT)*(Dh^3)/(kVis^2);% Solar Book, Grasshof number at ...
    NOCT
Nu_NOCT = 0.21*(Gr_NOCT + Pr).^0.32;% Solar Book, Nusselt number at NOCT
h_free_NOCT = Nu_NOCT*kT/Dh; % Solar Book
%Front side heat transfer coefficient at NOCT
h_c_front_NOCT = (h_forced_NOCT.^3 + h_free_NOCT.^3).^(1/3); % Solar Book
T_sky_NOCT = 0.0552*(Ta_NOCT)^(3/2); %Solar Book, Sky temperature at NOCT

%Ratio between front and back heat transfer coefficients at NOCT
R = ...
     (alfa*Gm_NOCT-h_c_front_NOCT*(T_NOCT-Ta_NOCT)-emi_front*Sb*(T_NOCT^4-T_sky_NOCT^4))./...
     (h_c_front_NOCT*(T_NOCT-Ta_NOCT)+emi_back*Sb*(T_NOCT^4-Ta_NOCT^4));
R=R.*(R>0);
```

```
Gm = TotalIRBaseBS;
Tm = Ta; % Initial guess of the PV module temperature

for i = 1:10
    % Radiative Heat Transfer
    % radiative heat transfer coefficient between module and sky
    h_r_sky=emi_front*Sb*(Tm.^2 + Ta.^2).*(Tm + Ta);
    % radiative heat transfer coefficient between module and ground
    h_r_gr= emi_back*Sb*(Tm.^2 + Ts.^2).*(Tm + Ts);

    % Free Convection
    Gr = max(0,(g*(1./Ta).*(Tm-Ta)*Dh^3/(muair^2))); %Grasshof number
    Nu = 0.21*(Gr*Pr).^0.32; %Nusselt number
    h_free = (Nu*kT)/Dh;

    % Calculate the total convective heat transfer coefficienct from the front and back ...
        surfaces
    h_c_front= (h_forced.^3 + h_free.^3).^(1/3);
    h_c_back = R.*h_c_front;
    h_c = h_c_back + h_c_front;
    Tm = (alfa*Gm + h_c.*Ta + h_r_sky.*Tsky + h_r_gr.*Ts)./(h_c + h_r_sky + h_r_gr);
end

%% Plotting the temperature of the module surface
figure(2)
plot(Tm,'color',[0.0, 0.6, 0.5])
xlim([0,8760])
xlabel('Hours of the year')
ylabel('Temperature [Celcius]')
x0=10;
y0=10;
width=1100;
height=400;
set(gcf,'position',[x0,y0,width,height])

% data regaring the module temperature
minTm = min(Tm);
maxTm = max(Tm);
meanTm = mean(Tm);

%% Efficiency after temp correction
MPPT_Eff = 0.99;      % Efficiency MPPT
Inv_Eff = 0.97;       % Efficiency inverter
Cable_Eff = 0.99;     % Cable losses

% changing the efficiency depending on temperature
for h = 1:8760
    HourlyOutputTempCorSS(h) = HourlyPowerOutputSingleBaseSS(h) + ...
        HourlyPowerOutputSingleBaseSS(h).*(Tm(h)-44).*(-0.003);
end
AnnualOutputWithTempCorrectionSS = sum(HourlyOutputTempCorSS);

for h = 1:8760
    HourlyOutputTempCorBS(h) = HourlyPowerOutputSingleBaseBS(h) + ...
        HourlyPowerOutputSingleBaseBS(h).*(Tm(h)-44).*(-0.003);
end
AnnualOutputWithTempCorrectionBS = sum(HourlyOutputTempCorBS);
AAnnualOutputWithTempCorrectionSS = ...
    sum(HourlyOutputTempCorSS)*(MPPT_Eff)*(Inv_Eff)*(Cable_Eff)
AAnnualOutputWithTempCorrectionBS = ...
    sum(HourlyOutputTempCorBS)*(MPPT_Eff)*(Inv_Eff)*(Cable_Eff)
AAOutputSS = AAnnualOutputWithTempCorrectionSS*nModulesBaseSS
AAOutputBS = AAnnualOutputWithTempCorrectionBS*nModulesBaseBS

% hourly output of total system:
HourlyOutputSystemAfterTempCor = ...
    (nModulesBaseSS*HourlyOutputTempCorSS+nModulesBaseBS*HourlyOutputTempCorBS); % ...
    after temp correction
HourlyOutputSystemAfterAllCor = ...
    HourlyOutputSystemAfterTempCor*(MPPT_Eff)*(Inv_Eff)*(Cable_Eff); % after all ...
    corrections
```

```
AnnualOutputSystemAfterTempCor = ...
    (nModulesBaseSS*AnnualOutputWithTempCorrectionSS+nModulesBaseBS*AnnualOutputWithTempCorrectionBS);
disp(['Total system annual output base scenario after temp.cor in MWh: ...
    ',num2str(AnnualOutputSystemAfterTempCor/10^6)]) % total output of SS and BS
AAOutputTotal = AAOutputSS+AAOutputBS
TotalOutputSystemAfterAllCorr = ...
    AnnualOutputSystemAfterTempCor*(MPPT_Eff)*(Inv_Eff)*(Cable_Eff)


for i = 1:365
    OutputDayRoofCorrected(i) = sum(HourlyOutputSystemAfterAllCor(1+24*(i-1):24*(i)));
end
for i = 1:52
    OutputWeekRoofCorrected(i) = sum(OutputDayRoofCorrected(1+7*(i-1):7*(i)));
end

p = polyfit(DaysYear,OutputDayRoofCorrected,4); %polyfit of the 4th order
DailyOutputFitCorrect = p(1)*x.^4 + p(2)*x.^3 + p(3)*x.^2 + p(4)*x + p(5);

figure(3)
plot(DaysYear,OutputDayRoofCorrected/1000,'color',[0 0.6 0.5],'LineWidth',2)
hold on
plot(DaysYear,DailyOutputFitCorrect/1000,'color',[0.5 0.5 0.5],'LineWidth',2)
ylabel('Power output [kWh/day]')
xlabel('Days')
legend( 'Corrected daily output','fitting')
xlim([0, 365])
x0=10;
y0=10;
width=1100;
height=400
set(gcf,'position',[x0,y0,width,height])
hold off

MaxInstantPowerOutput = max(HourlyOutputSystemAfterAllCor);

%% Compare differences
AnnualOutputWithTempCorrectionBS = sum(HourlyOutputTempCorBS);
TotalLossPPDueTempSS = ...
    (AnnualOutputWithTempCorrectionSS-AnnualPowerOutputSingleBaseSS)/AnnualOutputWithTempCorrectionSS;
TotalLossPPDueTempBS = ...
    (AnnualOutputWithTempCorrectionBS-AnnualPowerOutputSingleBaseBS)/AnnualOutputWithTempCorrectionBS;

%% flat roofed solar path (SPF)
clc
nPanelsSP1 = 3*25; % amount panels at section 1
nPanelsSP2 = 3*12;  % amount panels at section 2
nPanelsSP3 = 3*0; % amount panels at section 3
nModules_SPF = nPanelsSP1+nPanelsSP2+nPanelsSP3; % total amount of panels at SPF

Tilt_SPF = 15; % tilt of the flat roofs
Azi_SPF = 212; %Average Azimuth of4 flat roofs

AOI_SPF = pvl_getaoi(Tilt_SPF,Azi_SPF,SunZen,SunAz);  %angle of irradiance solar path ...
    flat roof.
% the different components of irradiance at SPF
SkyDiffuse_SPF = pvl_reindl1990(Tilt_SPF, Azi_SPF, DHI, DNI, GHI, Hextra, SunZen, SunAz);
GR_SPF = pvl_grounddiffuse(Tilt_SPF,GHI,Albedo);
DR_SPF = DNI.*cos(AOI_SPF.*(pi/180));

TotalIR_SPF = DR_SPF + SkyDiffuse_SPF + GR_SPF;       %irradiance experienced at SP [W/m^2]
TotIR_Single_SPF = sum(TotalIR_SPF);                  %total annual irradiance at SP ...
    [W/m^2]
HourlyPowerOutputSingle_SPF = TotalIR_SPF*EffPanel*oppPanel;          %hourly power ...
    output of single panel at SP [Wh]
HourlyPowerOutputTotalSPF = TotalIR_SPF*EffPanel*oppPanel*nModules_SPF/1000; % hourly ...
    output of total SPF [kWh]

AnnualPowerOutputSingle_SPF = sum(HourlyPowerOutputSingle_SPF);       %annual power ...
    output of single panel SP [Wh]

```

```
AnnualPowerOutputTotal_SPF = nModules_SPF*AnnualPowerOutputSingle_SPF/10^6;   %total ...
    annual output of all panels combined at seaside [MWh]
disp(['Annual output of total SPF without correction: ...
    ',num2str(AnnualPowerOutputTotal_SPF),' MWh'])
disp(['Annual output of single panel SPF: ',num2str(AnnualPowerOutputSingle_SPF/10^6),' ...
    MWh'])

%TotalPanelPrice_SP = nModules_SPF*PanelPrice;
%disp(['Total price of the panels: ',num2str(TotalPanelPrice_SP),' Euro'])


for h = 1:8760
    HourlyOutputTempSPF(h) = HourlyPowerOutputTotalSPF(h) + ...
        HourlyPowerOutputTotalSPF(h).*(Tm(h)-25).*(-0.003);
end

HourlyOutputSPF_AfterAllCor = HourlyOutputTempSPF*(MPPT_Eff)*(Inv_Eff)*(Cable_Eff);

for i = 1:365
    OutputDayCorrectedSPF(i) = sum(HourlyOutputSPF_AfterAllCor(1+24*(i-1):24*(i)));
end

for i = 1:365
    OutputDaySPF(i) = sum(HourlyPowerOutputTotalSPF(1+24*(i-1):24*(i)));
end

TotalAnnualSPF = sum(OutputDayCorrectedSPF/1000);
disp(['Annual output of total SPF with correction: ',num2str(TotalAnnualSPF),' MWh'])

for i = 1:52
    WeeklyOutputTotalCorrectedSPF(i) = sum(OutputDayCorrectedSPF(1+7*(i-1):7*(i)));
end

%% solar path tilted (SPT) with sections at their maximum tilt for path section azimuth
% all the Azimuth and related optimum tilt angles
AziSPT1 = 215; % close to irmao
AziSPT2 = 208; % middle section
AziSPT3 = 226; % closest to the parking lot

MaxIRFixedAzimuthSPT1 = max(IR(:,AziSPT1));
[Tilt_SPT1,AziSPT1]= find(IR==MaxIRFixedAzimuthSPT1);
MaxIRFixedAzimuthSPT2 = max(IR(:,AziSPT2));
[Tilt_SPT2,AziSPT2]= find(IR==MaxIRFixedAzimuthSPT2);
MaxIRFixedAzimuthSPT3 = max(IR(:,AziSPT3));
[Tilt_SPT3,AziSPT3] = find(IR==MaxIRFixedAzimuthSPT3);

Tilt_SPT1 = 10; % tilt of all the panels
Tilt_SPT2 = 10;
Tilt_SPT3 = 10;
% irradiance per panel per hour of the year for the sections
% section SPT1:
AOI_SPT1 = pvl_getaoi(Tilt_SPT1,AziSPT1,SunZen,SunAz);  %angle of irradiance solar path ...
    flat roof.
% the different components of irradiance at SPF
SkyDiffuse_SPT1 = pvl_reindl1990(Tilt_SPT1, AziSPT1, DHI, DNI, GHI, Hextra, SunZen, ...
    SunAz);
GR_SPT1 = pvl_grounddiffuse(Tilt_SPT1,GHI,Albedo);
DR_SPT1 = DNI.*cos(AOI_SPT1.*(pi/180));

TotalIR_SPT1 = DR_SPT1 + SkyDiffuse_SPT1 + GR_SPT1;  %hourly irradiance at SPT1 [W/m^2]
TotIR_Single_SPT1 = sum(TotalIR_SPT1);               %total annual irradiance at SPT1 ...
    [Wh/m2
HourlyPowerOutputSingle_SPT1 = TotalIR_SPT1*EffPanel*oppPanel; % Hourly output SPT1 ...
    [W/m^2]
HourlyPowerOutputTotalSPT1 = HourlyPowerOutputSingle_SPT1*nPanelsSP1; % hourly total ...
    output SPT3
AnnualPowerOutputSingle_SPT1 = sum(HourlyPowerOutputSingle_SPT1);   %annual power ...
    output of single panel SPT2 [Wh]
AnnualPowerOutputTotal_SPT1 = nPanelsSP1*AnnualPowerOutputSingle_SPT1/10^6;   %total ...
    annual output of all panels combined SPT1 [MWh]
disp(['Annual output of total SPT1: ',num2str(AnnualPowerOutputTotal_SPT1),' MWh'])
```

```matlab
disp(['Annual output of single panel SPT1: ...
      ',num2str(AnnualPowerOutputSingle_SPT1/10^6),' MWh'])

% section SPT2
AOI_SPT2 = pvl_getaoi(Tilt_SPT2,AziSPT2,SunZen,SunAz);  %angle of irradiance solar path ...
      flat roof.
% the different components of irradiance at SPF
SkyDiffuse_SPT2 = pvl_reindl1990(Tilt_SPT2, AziSPT2, DHI, DNI, GHI, Hextra, SunZen, ...
      SunAz);
GR_SPT2 = pvl_grounddiffuse(Tilt_SPT2,GHI,Albedo);
DR_SPT2 = DNI.*cos(AOI_SPT2.*(pi/180));

TotalIR_SPT2 = DR_SPT2 + SkyDiffuse_SPT2 + GR_SPT2;   %hourly irradiance at SPT2 [W/m^2]
TotIR_Single_SPT2 = sum(TotalIR_SPT2);                 %total annual irradiance at SPT2 ...
      [Wh/m2
HourlyPowerOutputSingle_SPT2 = TotalIR_SPT2*EffPanel*oppPanel; % Hourly output SPT2 ...
      [W/m^2]
HourlyPowerOutputTotalSPT2 = HourlyPowerOutputSingle_SPT2*nPanelsSP2; % hourly total ...
      output SPT2
AnnualPowerOutputSingle_SPT2 = sum(HourlyPowerOutputSingle_SPT2);   %annual power ...
      output of single panel SPT2 [Wh]
AnnualPowerOutputTotal_SPT2 = nPanelsSP2*AnnualPowerOutputSingle_SPT2/10^6;   %total ...
      annual output of all panels combined SPT2 [MWh]
disp(['Annual output of total SPT2: ',num2str(AnnualPowerOutputTotal_SPT2),' MWh'])
disp(['Annual output of single panel SPT2: ...
      ',num2str(AnnualPowerOutputSingle_SPT2/10^6),' MWh'])

% section SPT3
AOI_SPT3 = pvl_getaoi(Tilt_SPT3,AziSPT3,SunZen,SunAz);  %angle of irradiance solar path ...
      flat roof.
% the different components of irradiance at SPF
SkyDiffuse_SPT3 = pvl_reindl1990(Tilt_SPT3, AziSPT3, DHI, DNI, GHI, Hextra, SunZen, ...
      SunAz);
GR_SPT3 = pvl_grounddiffuse(Tilt_SPT3,GHI,Albedo);
DR_SPT3 = DNI.*cos(AOI_SPT3.*(pi/180));

TotalIR_SPT3 = DR_SPT3 + SkyDiffuse_SPT3 + GR_SPT3;   %hourly irradiance at SPT3 [W/m^2]
TotIR_Single_SPT3 = sum(TotalIR_SPT3);                 %total annual irradiance at SPT3 ...
      [Wh/m2
HourlyPowerOutputSingle_SPT3 = TotalIR_SPT3*EffPanel*oppPanel; % Hourly output SPT3 ...
      [W/m^2]
HourlyPowerOutputTotalSPT3 = HourlyPowerOutputSingle_SPT3*nPanelsSP3; % hourly total ...
      output SPT3
AnnualPowerOutputSingle_SPT3 = sum(HourlyPowerOutputSingle_SPT3);   %annual power ...
      output of single panel SPT3 [Wh]
AnnualPowerOutputTotal_SPT3 = nPanelsSP3*AnnualPowerOutputSingle_SPT3/10^6;   %total ...
      annual output of all panels combined SPT2 [MWh]
disp(['Annual output of total SPT3: ',num2str(AnnualPowerOutputTotal_SPT3),' MWh'])
disp(['Annual output of single panel SPT3: ...
      ',num2str(AnnualPowerOutputSingle_SPT3/10^6),' MWh'])

% All sections combined of SPT
AnnualPowerOutputTotal_SPT = ...
      AnnualPowerOutputTotal_SPT1+AnnualPowerOutputTotal_SPT2+AnnualPowerOutputTotal_SPT3;
HourlyPowerOutputTotal_SPT = ...
      HourlyPowerOutputSingle_SPT1+HourlyPowerOutputSingle_SPT2+HourlyPowerOutputSingle_SPT3;
disp(['Annual output of total SPT: ',num2str(AnnualPowerOutputTotal_SPT),' MWh'])

for h = 1:8760
    HourlyOutputTempSPT1(h) = HourlyPowerOutputTotalSPT1(h) + ...
        HourlyPowerOutputTotalSPT1(h).*(Tm(h)-25).*(-0.003);
    HourlyOutputTempSPT2(h) = HourlyPowerOutputTotalSPT2(h) + ...
        HourlyPowerOutputTotalSPT2(h).*(Tm(h)-25).*(-0.003);
    HourlyOutputTempSPT3(h) = HourlyPowerOutputTotalSPT3(h) + ...
        HourlyPowerOutputTotalSPT3(h).*(Tm(h)-25).*(-0.003);
end

HourlyOutputSPT1_AfterAllCor = HourlyOutputTempSPT1*(MPPT_Eff)*(Inv_Eff)*(Cable_Eff);
HourlyOutputSPT2_AfterAllCor = HourlyOutputTempSPT2*(MPPT_Eff)*(Inv_Eff)*(Cable_Eff);
HourlyOutputSPT3_AfterAllCor = HourlyOutputTempSPT3*(MPPT_Eff)*(Inv_Eff)*(Cable_Eff);
```

```
for i = 1:365
    OutputDayCorrectedSPT1(i) = sum(HourlyOutputSPT1_AfterAllCor(1+24*(i-1):24*(i)));
    OutputDayCorrectedSPT2(i) = sum(HourlyOutputSPT2_AfterAllCor(1+24*(i-1):24*(i)));
    OutputDayCorrectedSPT3(i) = sum(HourlyOutputSPT3_AfterAllCor(1+24*(i-1):24*(i)));
end

DailyOutputTotal_CorrectedSPT = ...
    OutputDayCorrectedSPT1+OutputDayCorrectedSPT2+OutputDayCorrectedSPT3;
TotalAnnualSPT = sum(DailyOutputTotal_CorrectedSPT/10^6);
disp(['Annual output of total SPT with correction: ',num2str(TotalAnnualSPT),' MWh'])
disp(['Annual output of total SPF with correction: ',num2str(TotalAnnualSPF),' MWh'])

% back to weeks
for i = 1:52
    WeeklyOutputTotalCorrectedSPT = sum(DailyOutputTotal_CorrectedSPT(1+7*(i-1):7*(i)));
end

disp(['total irradaince per m^2 = ' , num2str(TotIR_Single_SPT1/1000),' kWh'])
disp(['total irradaince per m^2 = ' , num2str(TotIR_Single_SPT2/1000),' kWh'])
disp(['total irradaince per m^2 = ' , num2str(TotIR_Single_SPT3/1000),' kWh'])

%% Final plotting, total production and consumption
Roof_Generation_Week = OutputWeekRoofCorrected
SPF_Generation_Week = WeeklyOutputTotalCorrectedSPF*10^3;
Consumption_Week = AdjustedElecConsumpWeek*10^3*(10/8);

for i = 1:52
    TotalProductionIrmao(i) = Roof_Generation_Week(i)+SPF_Generation_Week(i);
end

TotalGeneration  = sum(TotalProductionIrmao);      % total production
TotalConsumption = sum(Consumption_Week) ;         % total consumption

for i = 1:52
    if Consumption_Week(i) > TotalProductionIrmao(i)
        DemandSurplus(i) = Consumption_Week(i) - TotalProductionIrmao(i);
    else
        DemandSurplus(i) = 0;
    end
end
TotalDemandSurplus = sum(DemandSurplus);

for i = 1:52
    if Consumption_Week(i) < TotalProductionIrmao(i)
        GenerationSurplus(i) = TotalProductionIrmao(i) - Consumption_Week(i);
    else
        GenerationSurplus(i) = 0;
    end
end
TotalGenerationSurplus = sum(GenerationSurplus);

figure(4)
bar(WeeksYear,GenerationSurplus/10^6,'FaceColor',[0 0.6 0.5],'EdgeColor',[0 0 ...
    0],'LineWidth',0.5)
hold on
bar(WeeksYear,(-1)*DemandSurplus/10^6,'FaceColor',[0 0.6 0.5],'EdgeColor',[0 0 ...
    0],'LineWidth',0.5)
xlabel('Weeks')
ylabel('Surplus [MWh]')
x0=10;
y0=10;
width=1100;
height=400
set(gcf,'position',[x0,y0,width,height])

%% Final figure
figure(5)
plot(WeeksYear,Consumption_Week/10^6,'color',[0, 0, 0],'LineWidth',1.5)            ...
    % Consumption of roof and solarpath combined
hold on
```

```
plot(WeeksYear,TotalProductionIrmao/10^6,'color',[0.0, 0.6, 0.5],'LineWidth',1.5)   % ... production of electricity
plot(WeeksYear,SPF_Generation_Week/10^6,'--','color',[0, 0.6, 0.5],'LineWidth',1.5)   ... % SPF production
plot(WeeksYear,Roof_Generation_Week/10^6,'-.','color',[0, 0.6, 0.5],'LineWidth',1.5)   ... % roof production
ylabel('Consumption and production [MWh/Week]')
xlabel('Weeks')
x = DaysYear;
legend( 'Consumption','Total production', 'Solar path', 'Roof system')
xlim([0, 52])
x0=10;
y0=10;
width=1100;
height=400
set(gcf,'position',[x0,y0,width,height])
hold off

disp(['Annual output solar path: ',num2str(sum(SPF_Generation_Week)/10^6),' MWh'])
disp(['Annual output roof: ',num2str(sum(Roof_Generation_Week)/10^6),' MWh'])
disp(['Annual output total: ',num2str(TotalGeneration/10^6),' MWh'])
disp(['Annual consumption: ',num2str(TotalConsumption/10^6),' MWh'])

%% solar path with optimal tilted and optimal azimuth panels on poles (SPP)
nPanelsSPP = 58; % amount of panels on poles with poles being 2.6m seperated
HourlyPowerOutputSingle_SPP = HourlyPowerOutputSingle_OA;

AnnualPowerOutputSingle_SPP = sum(HourlyPowerOutputSingle_SPP);   %annual power output ... of single panel SPP [Wh]
AnnualPowerOutputTotal_SPP = nPanelsSPP*AnnualPowerOutputSingle_SPP/10^6;   %total ... annual output of all panels combined SPP [MWh]
disp(['Annual output of single panel SPP: ',num2str(AnnualPowerOutputSingle_SPP/10^6),' ... MWh'])
disp(['Annual output of total SPP: ',num2str(AnnualPowerOutputTotal_SPP),' MWh'])
```

E.3. Cover model electricity

```
% cover model for irmao
% based on data delivered by Irmao
% 04-10-2021

%% Weekly Regression only weekly data
WeeklyDataElec = [1856   1800;
2208      1987;
2426      2050;
2051      1782;
1851      1670;
2137      1692;
1828      595;
983       336;
983       336]; % combined data from invoices and measurements

kWh = WeeklyDataElec(:,1);
Cov = WeeklyDataElec(:,2);

x = linspace(1,2500,2500);  % creating interval for fitting of consumption vs covers
q = polyfit(Cov,kWh,1);     % First order fitting
fit1 = q(1)*x + q(2);
p = polyfit(Cov,kWh,2);     % Second order fitting
fit2 = p(1)*x.^2 + p(2)*x + p(3);

daily1st = fit1/6;           % Deviding weekly fit by number of operating days per week
daily2nd = fit2/6;          % Deviding weekly fit by number of operating days per week


figure(1)
scatter(Cov,kWh,'x','MarkerEdgeColor',[0 0 0],...
               'MarkerFaceColor',[1 1 1],'LineWidth',0.6);
```

```
hold on
%plot(x,fit1)
plot(x,fit1,'-','color', [0 0.6 0.5],'LineWidth',1.5)
plot(x,fit2,'--','color', [0 0.6 0.5],'LineWidth',1.5)
ylabel('Electricity [kWh]')
xlabel('Covers [-]')
xlim([0,2500])
ylim([0,2500])
legend('Data points','1st order regression', '2nd order regression')
title('Electricity consumption vs. covers')
box on
x0=10;
y0=10;
width=1100;
height=400
set(gcf,'position',[x0,y0,width,height])

%% The regression vs the covers
LoadCovers = load('CoversEstimated')
CoversEstimated = LoadCovers.EstimatedCovers(:,1)
x = linspace(1,52,52);
i = CoversEstimated;
ElecConsumpWeek = p(1)*i.^2 + p(2)*i + p(3);     % 2nd order polynomial of consumption ...
    vs covers

% Adjusted to closed weeks
AdjustedElecConsumpWeek = ElecConsumpWeek;  % make up for the weeks of total closure in ...
    February

for i = 1:52
    if AdjustedElecConsumpWeek(i) < 900    % removing values when totally closed
        AdjustedElecConsumpWeek(i) = 50;    % estimation of the consumption during ...
            closure
    else
    end
end

figure(3)                        % Plotting adjusted vs covers
yyaxis left
b = bar(x,CoversEstimated,'FaceColor',[0.8 0.8 0.8],'EdgeColor',[0 0 0],'LineWidth',0.5)
ylabel('Covers [-]')
xlabel('Weeks [-]')
ylim([0,2700])
xlim([0,53])

yyaxis right
p = plot(x,AdjustedElecConsumpWeek,'color',[0 0.6 0.5],'LineWidth',2)
ylabel('Electricity [kWh]')
xlabel('Months [-]')
ylim([0,2700])

title('Weekly covers and consumption of electricity')
ax = gca;
ax.YAxis(1).Color = 'k';
ax.YAxis(2).Color = [0 0.6 0.5];
xticks([2.2,6.5,10.8,15.2,19.5,23.8,28.2,32.5,36.8,41.2,45.5,49.8])
xticklabels({'Jan','Feb','Mar','Apr','May','Jun','Jul','Aug','Sep','Okt','Nov','Dec'})
legend('Covers','Electricity consumption')
x0=10;
y0=10;
width=1100;
height=400
set(gcf,'position',[x0,y0,width,height])

AdjustedAnnualConsElec = sum(AdjustedElecConsumpWeek)         % kWh year
CO2PerMWh = 241                                               % g/kWh
AnnualCo2Production = CO2PerMWh*AdjustedAnnualConsElec/10^6   % tonCO2/year
```

E.4. Cover model water

```
% Water vs. covers
% Based on data from measurements and invoices


WeeklyDataWater = [242   18.44;
94        12.06;
100       9.25;
257       11.20;
1126      22.03;
1193      22.86;
1432      26.90;
1350      25.82;
1621      29.40;
1601      29.14;
1268      24.74;
1629      28.50;
1428      24.46;
1519      25.38;
1743      17.65;
1800      33.90;
1562      30.47;
2219      39.93;
2210      39.80;
2525      44.33];

Water = WeeklyDataWater(:,2);
Cov = WeeklyDataWater(:,1);

x = linspace(1,2500,2500);      % creating interval for fitting of consumption vs covers
q = polyfit(Cov,Water,1);       % First order fitting
fit1 = q(1)*x + q(2);
p = polyfit(Cov,Water,2);       % Second order fitting
fit2 = p(1)*x.^2 + p(2)*x + p(3);

figure(1)
scatter(Cov,Water,'x','MarkerEdgeColor',[0 0 0],...
               'MarkerFaceColor',[1 1 1],'LineWidth',0.6);
hold on
plot(x,fit1,'--','color', [0 0.6 0.5],'LineWidth',1.5)
plot(x,fit2,'-','color', [0 0.6 0.5],'LineWidth',1.5)
ylabel('Water [m^3]')
xlabel('Covers [-]')
xlim([0,2500])
ylim([0,50])
legend('Data points','1st order regression', '2nd order regression')
title('Water consumption vs. covers')
x0=10;
y0=10;
width=1100;
height=400
set(gcf,'position',[x0,y0,width,height])
box on

%% year vs covers vs water consumption

LoadCovers = load('CoversEstimated')
CoversEstimated = LoadCovers.EstimatedCovers(:,1)
x = linspace(1,52,52);

i = CoversEstimated;
WaterConsumpWeek = p(1)*i.^2 + p(2)*i + p(3);

AdjustedWaterConsumpWeek = WaterConsumpWeek;  % make up for the weeks of total closure ...
    in February

for i = 1:52
    if AdjustedWaterConsumpWeek(i) < 12      % removing values when totally closed
```

```
        AdjustedWaterConsumpWeek(i) = 3.25;    % estimation of the consumption during ...
            closure
    else
    end
end

figure(3)              % Plotting adjusted vs covers
yyaxis left
b = bar(x,CoversEstimated,'FaceColor',[0.8 0.8 0.8],'EdgeColor',[0 0 0],'LineWidth',0.5)
ylabel('Covers [-]')
xlabel('Weeks [-]')
ylim([0,2700])
xlim([0,53])

yyaxis right
plot(x,AdjustedWaterConsumpWeek,'color',[0 0.6 0.5],'LineWidth',2)
ylabel('Water [m^3]')
xlabel('Months [-]')
ylim([0,55])

title('Weekly covers and consumption of water')
ax = gca;
ax.YAxis(1).Color = 'k';
ax.YAxis(2).Color = [0 0.6 0.5];
xticks([2.16, 6.5, 10.8, 15.12, 19.44, 23.76, 28.08, 32.4, 36.72, 41.04, 45.4 ,49.68])
xticklabels({'Jan','Feb','Mar','Apr','May','Jun','Jul','Aug','Sep','Okt','Nov','Dec'})
legend('Covers','Water consumption')
```

E.5. Cover model waste

```
% Waste vs. covers
% Based on data from measurements and invoices


WeeklyDataWaste = [374  125.7333;
374 125.7333;
374 125.7333;
374 125.7333;
0   0;
0   0;
0   0;
0   0;
213 97.43636;
213 97.43636;
213 97.43636;
534 153.8545;
534 153.8545;
534 153.8545;
534 153.8545;
534 153.8545;
687 180.7455;
1430    311.3333;
1430    311.3333;
1494    322.5818;
1557    333.6545;
1621    344.903;
1601    341.3879;
1581    337.8727;
1560    334.1818;
1540    330.6667;
1519    326.9758;
1743    366.3455;
1800    376.3636;
1981    408.1758;
2163    440.1636;
2344    471.9758;
2525    503.7879;
2288    462.1333;
```

```
2050    420.303;
1782    373.2;
1680    355.2727;
1692    357.3818;
1647    349.4727;
1466    317.6606;
1466    317.6606;
1466    317.6606;
1466    317.6606;
1466    317.6606;
393 129.0727;
393 129.0727;
393 129.0727;
393 129.0727;
353 122.0424;
353 122.0424;
353 122.0424;
353 122.0424]

Wast = WeeklyDataWaste(:,2);
Cov = WeeklyDataWaste(:,1);

x = linspace(1,52,52);      % creating interval for fitting of consumption vs covers

%% year vs covers vs water consumption

figure(3)               % Plotting adjusted vs covers
yyaxis left
b = bar(x,Cov,'FaceColor',[0.8 0.8 0.8],'EdgeColor',[0 0 0],'LineWidth',0.5)
ylabel('Covers [-]')
xlabel('Weeks [-]')
ylim([0,2700])
xlim([0,53])

yyaxis right
plot(x,Wast,'color',[0 0.6 0.3],'LineWidth',2)
ylabel('Waste [kg]')
xlabel('Months [-]')
ylim([0,700])

title('Weekly covers and production of waste')
ax = gca;
ax.YAxis(1).Color = 'k';
ax.YAxis(2).Color = [0 0.6 0.3];
xticks([2.16, 6.5, 10.8, 15.12, 19.44, 23.76, 28.08, 32.4, 36.72, 41.04, 45.4 ,49.68])
xticklabels({'Jan','Feb','Mar','Apr','May','Jun','Jul','Aug','Sep','Okt','Nov','Dec'})
legend('Covers','Waste production')
```

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