

IOT, MACHINE LEARNING AND PHOTOGRAMMETRY IN SMALL HYDROPOWER TOWARDS ENERGY AND DIGITAL TRANSITION: POTENTIAL ENERGY AND VIABILITY ANALYSES

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Abstract:

This research aims to evaluate and put into practise the design of a small hydropower plant on a stream at São Vicente, in Madeira Island, supported by internet of things (IoT). The photogrammetry technique is also used with a comprehensive digital transformation, in which new concepts, methods and models, such as machine learning (ML), and big data analytics play an important role due to the huge availability time series that have to be exploited in hydropower design studies. Nowadays, digitalization and massive data availability are imposing new ways to address many of the current challenges associated with the energy and digital transition. This research is based on a simple small hydropower design, to present an integrated methodology using new methods assigned by an internet protocol system, which includes the development of different steps and components supported by GIS, photogrammetry and the use of advanced tools, with the support of a drone survey with internet communication (IoT) that allow the generation of experimentally-based estimates in situ characterization, the volumetric flow, the hydrological data treatment, the hydraulic calculations and economic estimations for a real hydro project. Therefore, hydrological variables, hydraulic analysis and topographical survey are carried out in the IoT application platform supported by new tools and methods to optimise the size of hydraulic structures, estimate the performance and potential of the hydropower plant towards the best solution for energy and digital transition. Firstly, the data-base for the all study and posterior sizing of the case study of hydropower plant are defined and then the corresponding analyses and results are presented. Then, the cost estimation for the construction, maintenance and operation of the selected elements that compose the hydropower topology are determined, as well as the respective economic balance, considering the annual energy production. In addition, both economic and environmental return on investment is discussed. Finally, an analysis to equate the cost estimates and the respective benefits of hydropower generation using this new approach applicability is established, taking into account some economic indicators to determine the profitability of the project.

Keywords: IoT; smart tools; photogrammetry; machine learning; viability design; small hydropower; energy and digital transition; internet protocol.

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1. Introduction

The Internet of Things (IoT) is a system of interconnected data processing devices (Afzal et al., 2019), for mechanical and digital machines, objects, animals, or people that are tagged with unique identifiers (UIDs) and can transmit data over a network without requiring human-to-human or human-to-computer interaction. An Internet of Things (IoT) can be a person with a heart monitor implant, a farm animal with a biochip transponder, a car with built-in sensors that warn the driver when the tire pressure is low, or any other natural or man-made object that can be assigned an Internet Protocol (IP) address and it is capable of transmitting data over a network.

Companies across a wide range of industries are increasingly using the Internet of Things to operate more efficiently, and to better understand and serve their customers, improve decision-making and add value to

the business. Small hydropower plants attempt to convert the energy available in a hydraulic gravity system into electrical energy. Since this generation does not use fossil fuels, it offers numerous social and environmental benefits, contributing to the development of a region and to the global energy transition.

Planet Earth is increasingly facing new technical, social and environmental challenges, being one of the most important and topical of which is that of sustainability, digital and energy transition to renewable sources complemented with new tools, such as IoT. In recent decades, renewable energy has proven to be the cleanest and most sustainable solution compared to traditional generation and sometimes to the outdated system of burning fossil fuels.

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The purpose of a hydropower project depends on local conditions, such as available natural resources and geological and topographical conditions, but also, on the implementation of the different components. Depending on the production capacity of the project, the energy generated used in a stand-alone solution or can be sold and supplied into the national grid.

The technical and economic viability project analyses are essential at an early stage, as they allow the development of an estimative of the costs and benefits, evaluate the profitability and feasibility of the hydropower exploitation, and thus provide a conclusion on whether the project is viable and attracts the interest of potential investors.

An IoT ecosystem consists of web-enabled smart devices that use embedded systems such as processors, sensors, and communications hardware to collect, send, and process data from their environment. IoT devices share the collected sensor data by connecting to an IoT gateway or other edge device, where the data is either sent to the cloud for analysis or analysed locally. Sometimes these devices also communicate with other related devices and use the information they receive from each other. The devices do most of the work without human intervention, although humans can interact with the devices - for example, to set them up, give them instructions, or access the data.

Small hydropower plants seek to transform the energy available from a gravity hydraulic system into electrical energy (<https://www.iea.org/reports/global-energy-review-2020> (accessed on 15 February 2021)). This production, as it does not use fossil fuels, has numerous social and environmental advantages, thus contributing to the development of the region and to the global energy transition. World or society in general, is increasingly facing new technical, social and environmental challenges, with one of the most important and current being related to sustainability. In recent decades, renewable energies have been the cleanest and most sustainable solution compared to traditional energy production and the obsolete system of burning fossil fuels. High population growth and increased consumer habits (i.e., increased demand for energy) led to the need for greater industrial production (supply), with the aim of satisfying the society costumers, as a whole. However, it was these political and economic pressures that were responsible for the exponential growth of technology that made it possible today to obtain yields and efficiencies that make it possible to reuse energy through new methods and new equipment.

The location of a small hydro plant is a factor of greater importance, since in order to have the possibility of hydroelectricity production, there is a need for proximity to a watercourse or the creation of a reservoir, as well as the existence of an adequate topographic difference level. The vast majority of small hydropower plants are of run-of-river, without retention or with low storage capacity. The purpose of a hydropower project depends on local conditions, not only the available natural resource and geological and topographical conditions, but also, on the implementation of its various project components (Kishore et al., 2020, 2021). Depending on the production capacity of the harness, the energy produced can be used locally

or sold and transferred to the national electricity grid. The technical-economic feasibility analysis is essential in an initial phase, since it allows the development of an estimate of costs and benefits, weighing the profitability and viability of the hydroelectric use, thus allowing to infer if the project is viable and if it captures the interest of potential investors. The flow of water is the main and determining factor in the production of water energy. hence the need to carry out previous studies on its availability and on the behaviour of the hydrological cycle. Both the topography of the site and its geographic location influence the amount of available water that can be used by hydroelectric plants. In order to enhance water energy recovery systems, it is necessary to carry out hydrological studies of the locations where these solutions will be implemented. The more in-depth the hydrological study is, the greater the reliability of the solution and the better correlation the project will have with reality. The correct accounting of the amount of water flowing in a given watercourse enables a more efficient design of a hydroelectric plant. The study of critical flood situations is equally important in designing the safety structures that complete a hydroelectric plant. There are two approaches to estimating the amount of water that can be harnessed to generate hydroelectric power. The most direct way to calculate the water flow would be to regularly survey the data, acquired through flow measurement stations (flow meters). However, this method is limited by the condition of its location. For a good quality of the data collected, there is a need for the station to be close to the study area. The other method of obtaining data is through the study of the hydrological balance of the zone. Precipitation, watershed area, evapotranspiration and local geology are the variants that allow the calculation of a balance that represents the values that are closest to reality.

A watershed consists of a certain area of flow of a specific watercourse and the tributary watercourses. The water flows naturally, taking advantage of gravity from the high points upstream, to the lowest convergent point downstream, where the limits of the watersheds coincide with the ridge lines. However, in permeable lands or susceptible to underground storage zones, the delimitation of basins is less linear.

Each basin can be divided into sections depending on the extent of its hydrographic network, to which each tributary has a respective reference section. The relief and shape of the hydrographic basin are factors that contribute to the variation in flow time and response time in flood situations. However, watercourses or precipitation can merely infiltrate the soil forming springs and groundwater or resulting in underground reservoirs known as aquifers, made up of rocks with porous and permeable characteristics. Others are just directed to different surfaces such as roads or sidewalks ending up in culverts, designated for storm drainage.

On the other hand, precipitation corresponds to the process by which water, in liquid or solid form. forms in the atmosphere and is subsequently transported to the earth's surface through rain, hail or snow. Precipitation is part of the water cycle and is extremely essential for man as he depends on it to obtain fresh water and consequently for his survival.

The water that is precipitated within a certain catchment area can be estimated through an udometer (counted in mm) being a priori strategically positioned in the catchment zone. The closer the study area is to the udometer position, the greater the accuracy of the values obtained. Evapotranspiration comes from the evaporation and transpiration, in its entirety, of everything that is found on the Earth's surface, being designated as the process of mutation of the water present in the Earth to the atmosphere.

The determining climatic factors that affect evapotranspiration are relative humidity, air temperature, wind speed and duration of sunlight. However, there are other factors that also have an impact on this process, such as: physical factors (substances contained in water, topographic characteristics of the region, among others), soil factors (distribution and moisture content in the soil and its physical and chemical characteristics) and vegetation factors.

Potential Evapotranspiration is defined by:

- (i) Thornthwaite, as being the amount of water that can pass into the atmosphere, directly or through the plants, if the existing moisture in the soil is always available, in sufficient quantity. For this reason, the type of vegetation cover and its degree of development have a great effect/consequence on evapotranspiration.
- (ii) Penman, as a uniform ground surface consisting of fresh grass, uniform height and green in colour. This process reduces a variable and makes the calculation of evapotranspiration depend solely on climatic factors and completely covered by fresh, green grass of uniform height.

Actual evapotranspiration is conditioned by the existence or not of sufficient amounts of water to allow this process. Actual evapotranspiration will always be less than or equal to potential evapotranspiration since, regardless of whether atmospheric conditions are favourable, it depends on the availability of water in the environment. Evaporation and evapotranspiration can be calculated using evaporimeters or using formulas (e.g., Thornthwaite, and Turc).

However, when a watercourse has installed hydrometric statins, then hydrological studies can be more robust compared to the application of precipitation-runoff models, since an important record of water flow permits to establish not only daily flow but also extreme situations to design weir and annexes structures. In this research, the application of precipitation-runoff models is applied in the analysed watershed.

2. Tools and studies

2.1. IoT and Theoretical Framework

The connectivity, networking and communication protocols used with these web-enabled devices largely depend on the specific IoT applications deployed. IoT can also make use of artificial intelligence (AI) and machine learning to aid in making data collecting processes easier and more dynamic (see Figure 1). Internet of Things offers several benefits to businesses. Some benefits

are industry-specific, while others are applicable across industries. Some of the general benefits of IoT enable companies to:

- Monitor their overall business processes;
- Improve the customer experience (CX);
- Save time and money;
- Increase employee productivity;
- Integrate and adapt business models;
- Make better business decisions and generate more revenue.

The IoT encourages companies to rethink their business approaches and gives them the tools to improve their business strategies.

In general, IoT is most prevalent in manufacturing, transportation. and utilities, where sensors and other IoT devices are used. However, there are also use cases in agriculture, infrastructure and home automation that are leading some companies to digital transformation (Gillis, 2021).

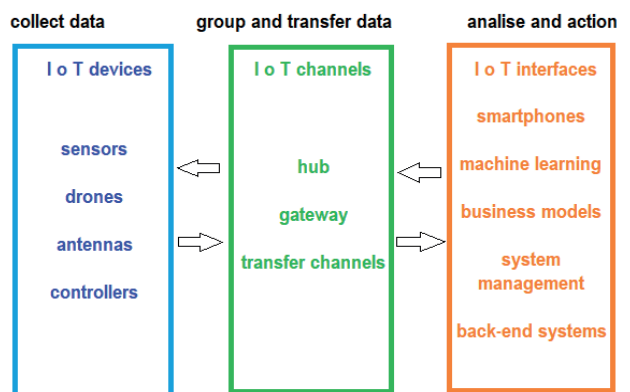


Figure 1: Scheme of IoT system.

Another tool used in this study is the photogrammetry as a science and technology of obtaining reliable information about physical components (such as locals, streams, environmental boundaries) through the process of recording, measuring and interpreting photographic images and patterns of electromagnetic radiant imagery, as shown in Figure 2.

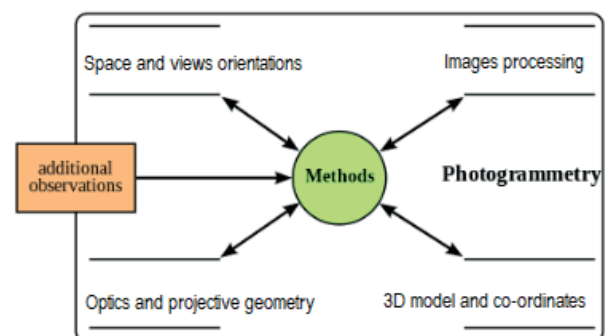


Figure 2: View model of photogrammetry.

2.2. Photogrammetry technique

Photogrammetry employs techniques from a variety of fields, such as optics and projective geometry. The process of capturing digital images and conducting photogrammetric analysis entails a number of clearly defined stages, which culminate in the creation of either 2D or 3D digital models of the object.

The 3D coordinates define the location of the object points in 3D space. The image coordinates define the positions of the images of the object points on the film or an electronic imaging device. The outer orientation of a camera defines its location in space and its viewing direction. The inner orientation defines the geometrical parameters of the imaging process. This is primarily the focal length of the lens, but can also include the description of lens distortions. Other additional considerations play an important role: With scales, basically, a known distance between two points in space, or known fixed points, the connection to the basic units of measurement is established. Each of the four main variables can be an input or an output of a photogrammetric method. Algorithms for photogrammetry typically attempt to minimize the sum of squared errors over the coordinates and relative displacements of the reference points. This minimization is known as bundle adjustment and is often performed using the Levenberg-Marquardt algorithm.

Photogrammetry technique seems to be more accurate in the x and y direction, while range data are generally more accurate in the z direction which can be supplied by techniques like laser scanners (using time of flight, triangulation or interferometry), white-light digitizers and any other technique that scans an area and returns Cartesian coordinates for multiple discrete points (commonly called "point clouds"). Photos can clearly define the edges of objects when the point cloud footprint cannot. In this study it was incorporated the advantages of both systems and integrate them to create a better product with a 3D visualization created by georeferencing the aerial photos. This technique helps significantly the engineering design under real nature environment.

2.3. Machine Learning

Machine Learning (ML) is a comprehensive digital transformation that can be applied in many areas of the energy sector. In which new concepts, methods and models are receiving more attention in management entities, academia and also in industry. Among these concepts, machine learning (ML), the Internet of Things (IoT), and Big Data analytics play an important role due to the massive availability of data that can be exploited for hydrologic studies and photogrammetry surveys (Brown, 2016; Cheng et al., 2019; Chiara et al., 2020). Digitization and massive data availability are opening up new ways to address many of the current challenges in the energy sector. They offer tools and digital approaches that will improve or even drastically change the currently established methods for analysis, simulation and optimization in the energy sector (Barros et al., 2003, Bathia and Sood, 2020). The global fleet of hydropower plants is adapting to a new era of digitised systems and processes, from design and construction

to operation and maintenance. Intelligent digital control systems can improve the performance and extend the life of hydropower plants. Operations and maintenance can be optimised and costs reduced through advanced performance monitoring analysis. However, a major challenge is to efficiently collect and analyse data to fully utilise and benefit from the information it contains. ML Techniques can be used to identify functional relationships between variables by analysing large amounts of potentially disparate Big Data (streaming measurements, batch data from measurement campaigns and metadata) and extracting beneficial information (Mitchell, 2017). In short-term hydropower scheduling (STHS) challenges in hydropower plants can broadly be classified as reservoir-based and run-of-river type. In a cascaded watercourse, there is a combination of storage reservoirs and run-of-river plants. Each reservoir is either connected to a water intake and associated to a hydropower plant component of different or identical hydro units. The hydro units can be generating or pumping units. The main source of inflow for hydropower plants comes from precipitation and streams.

ML is the field of study that gives computers the ability to learn without being explicitly programmed (Muñoz, 2014). A computer program is said to learn from experience E with respect to some task T and some performance measure P, if its performance on T, as measured by P, improves with experience E. Different ML methodologies have been applied to the field of hydropower scheduling, mainly for the purpose of dataset forecasting. Among these, the most widely used techniques found in the literature are Linear Regression (LR), Support Vector Machine (SVM), Support Vector Regression (SVR), Clustering, Fuzzy clustering, Artificial Neural Networks (ANNs) (Filo, 2023). Specifically, LR, SVM, and SVR fall under the umbrella of the so-called "supervised learning", while Clustering and Fuzzy clustering fall under the umbrella of the so-called "unsupervised learning". In addition, ANN is part of the more advanced "deep learning" approach. Supervised learning refers to an ML approach in which both input variables and output variables are available, and an algorithm is used to learn how to map functions from the inputs to the outputs. The objective of the learning algorithm is to get an approximation of the mapping function that is good enough to allow predictions of output variables when new input data arise. It is called supervised learning because it uses a training dataset to train the algorithm. The algorithm is then able to treat a new dataset according to the training experience.

2.4. Methodology for design

The methodology includes different issues: Data collection with the support of photogrammetry, topographic information, GIS for the survey and locals' identification, IoT for the communication and ML for analyses and correction values and definition of suitable big-data for the design conditions; Field campaign in situ is to correct some bad-defined values, and observe the real conditions of the watershed associated. All data from hydrologic parameters are also inputs for the ML tool based on National meteorologic information in terms of precipitation, evapotranspiration in order to apply the hydrologic balance model and estimate the suitable flow discharge design for the defined local to implant the small hydropower.

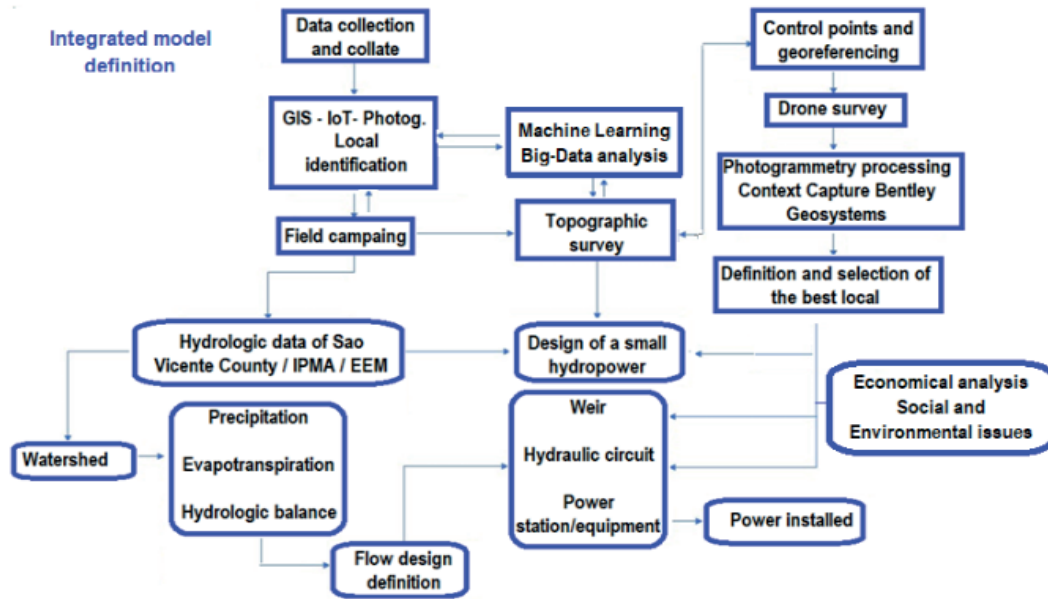


Figure 3: Methodology to estimate the power installed.

Then the integrated model proceeds to the design possibilities for the hydro scheme, optimising the position, critical points, and power installed based on economic studies, performance economic indicators, and social and environmental externalities. Figure 3 presents the used methodology.

2.5. Hydrologic-based fundamentals

In a given period of time, a watershed is fundamentally fed by precipitation and by water released by human action. Therefore, the water is drained, allowing evapotranspiration and water extraction by man. The amount of water existing in the hydrological network, that is, the water retained at the surface present in the form of soil moisture and the water stored in underground reserves, varies depending on the time interval to be considered. This is determined by the following equation:

$$P = H + E + \Delta SP + \Delta S + \Delta SU + EX - R \quad (1)$$

where P = precipitation present in the basin; H = calculated flow downstream thereof; E = evapotranspiration; ΔSP = variation of storage in the beds, the amount of water at intersection and surface detention; ΔS = variation in the amount of soil moisture; ΔSU = variation in the amount of water in underground reserves; EX = amount of water extracted from the basin by human action; and R = amount of water released into the basin by human action.

Figure 4 shows a scheme of the hydrological model used in this study.

If the water balance is calculated for a given interval that is sufficiently large, the variations of the different types of water storage in the basin can be neglected, that is, $\Delta SP = 0$; $\Delta S = 0$; and $\Delta SU = 0$. If there is no type of human intervention, that is, no water extracted or

discharged, $EX = 0$ and $R = 0$. In short, the hydrological balance would translate into $P = H + E$.

2.6. Hydraulic framework

Hydropower is a renewable energy source and consists of taking advantage of momentum and pressure (for reaction turbines) of water as a driving force, transforming gravitational potential energy into kinetic energy through the rotating movement of the turbine blades (Ferreira et al., 2016, Ramos, 2000). The rotating movement is then transmitted to the generator which transforms the mechanical energy into electrical energy, through the phenomenon called electromagnetic induction. Finally, useful energy is sent to the grid or consumed locally.

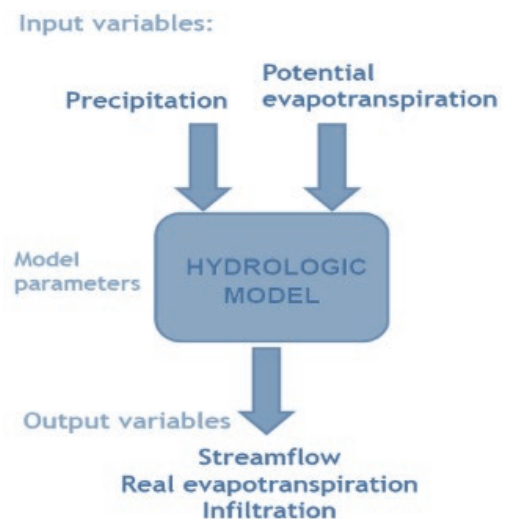


Figure 4: Hydrology model scheme.

Although hydropower is a renewable energy and therefore inexhaustible but limited, the possibility of negative impacts is always a factor to be taken into account (Gielen et al., 2019). Some strategies were then developed in order to guarantee the sustainability of this technological system, such as: the guarantee of an ecological flow downstream of the installation in order to safeguard the ecosystem, use of turbines that do not harm the well-being of the fish and reduction of sources of central noise from the equipment used in them.

The production of hydroelectric energy comes mainly from hydropower stations (Finardi and Silva, 2006). During the development phase of a small hydro project there are two main factors to consider: the topography and the hydrology of the site (Singh and Singal, 2017). It is these factors that will later allow the calculation of the entire system of a hydroelectric project, namely the choice of the turbine and the dimensions of the pipes and complementary structures.

Hydropower plants can be divided into three types:

- i) Run-of-river plants, being projected parallel to the water line through a diversion from the main channel. Despite being a lower cost option as they do not require large structures, they are conditioned by the flow of the river, which can in certain cases be irregular. As a rule, this type of solution is the most sustainable.
- ii) Plants with storage usually involve greater human intervention in the construction phase. It is necessary to build structures that store water in a higher area for later discharge. The great advantage of this type of plant is the ability to control the flow that runs through the system through gates or valves at the entrance of the ducts.
- iii) Reversible hydroelectric power plants, when there is excess electricity production capacity in periods of low consumption, this solution is used to transfer energy from one period to another, by pumping water from a lower reservoir to another located at a lower highest height.

Figure 5 shows the scheme elements that compose a penstock and power station elements.

In the channel component for small slopes (longitudinal slopes lower than 6°), turbulent flow and considering no lateral discharge and a prismatic canal with a longitudinal slope, the water profile can be obtained by using a finite difference technique (“standard step method”):

$$z_i + y_i + \frac{v_i^2}{2g} = z_{i+1} + y_{i+1} + \frac{v_{i+1}^2}{2g} + h_f + h_l \quad (2)$$

where z = invert elevation of a channel, y = water height, v = mean water velocity, g = gravitational acceleration, h_f = friction losses computed using Manning equation, and h_l = local losses due to expansion or contraction between cross-sectional areas.

For the penstock the Colebrook-White equation can be used to compute friction factor (f) along conduits. The

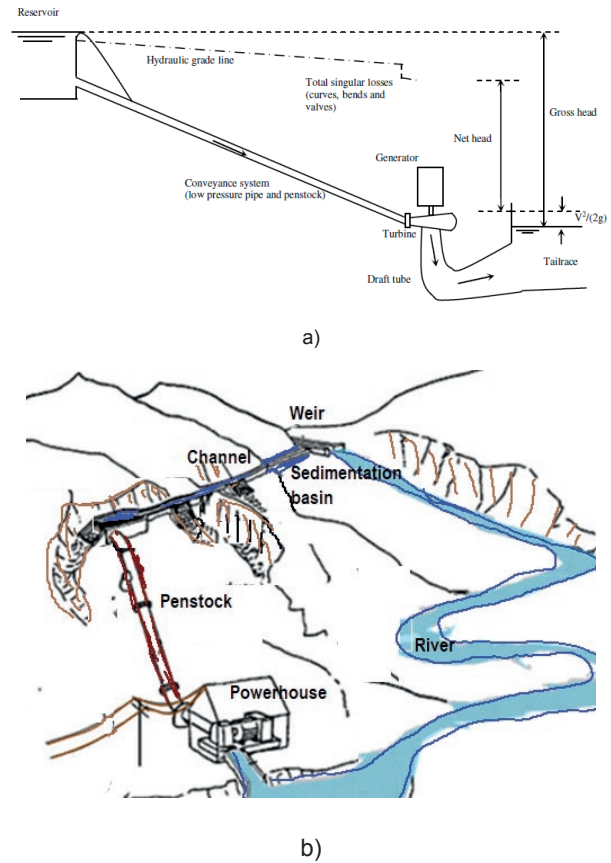


Figure 5: Scheme of a small hydropower solution: (a) penstock and powerhouse; (b) channel and connection to the penstock.

best approximation corresponds to the Swamee–Jain equation, which is presented below:

$$f = \frac{0.25}{\left[\log \left(\frac{k_s}{3.7D} + \frac{5.74}{\text{Re}^{0.9}} \right) \right]^2} \quad (3)$$

where k_s = absolute roughness, D = internal pipe of a conduit, and Re = Reynolds number.

After that, friction head losses (h_f) can be computed as follows:

$$h_f = \frac{8fLQ^2}{\pi^2gD^5} \quad (4)$$

where, L = total length of a conduit, Q = water flow inside of a conduit, and g = gravitational acceleration.

And for local head losses (h_L):

$$h_L = k_L \frac{Q^2}{2gA^2} \quad (5)$$

where, k_L = local head losses coefficient and A = cross-sectional area of a conduit.

For the turbine selection using the affinity laws for turbomachines, which represent the mathematical relationship between the rotational speed (N), flow rate

(Q), head (H) and pump power (P). The specific speed is given by:

$$n_s = n \frac{P^{1/2}}{H^{5/4}} \quad (6)$$

Being n_s the specific speed, which is a characteristic of each runner, the power turbine output capacity is given by

$$P = \frac{\gamma Q H}{\eta} \quad (7)$$

where γ = water unit weight, and η = system efficient.

3. IoT support and design flow

3.1. IoT and Geographical Context

The study site is located at Stream de São Vicente, in County of São Vicente, Madeira Island, Portugal. This stream is inserted in one of the largest watersheds of the Autonomous Region of Madeira (RAM) (Figure 6), with 37.54 km² and varies between elevation 0 and 1690 m.

The Madeira archipelago is of volcanic origin, having been generated by a “hot spot”, and its irregular and accentuated topography is quite noticeable. A quarter of the Madeira Island’s surface is located above 1000 m of altitude and that sensibly 65% of the surface has slopes of over 25%, with flat areas being almost non-existent.

Due to its distinct topographic and geological constitution, the rainwater drains directly and quickly into the sea, thus preventing the formation of natural surface reserves and consequently damaging agricultural and forestry areas in cases of torrential regimes. Having said this, it appears that there is a large number of springs distributed evenly throughout the island of Madeira, being particularly relevant and imposing those that are oriented north of it and between the elevations 600 and 1000 (Gaspar and Portela, 2002).

Regarding climatology, the average annual precipitation values increase with altitude, being generally higher on the northern side of the island than on the southern side, for the same altitude. The average annual relative humidity values are between 75% and 90%, except in the areas of Funchal and Lugar de Baixo which varies between 55 and 75%. Therefore, the steepness of slopes together with its tropical climatic conditions, create advantageous scenarios for hydroelectric exploitation.

Madeira Island due to its geological formation and geographical position presents conditions that allow energy production through various types of renewable energy, in particular wind, hydro, photovoltaic and waste. The primary energy sources in Madera Island are: thermal fuel power stations (51.6%), thermal power stations (20.8%), wind power (10.7%), hydroelectric plants (8.2%), waste generation (5.2%), and photovoltaic plant (3.5%). Currently, the energy production from non-fossil sources represents a little less than 30% of the total production of RAM.

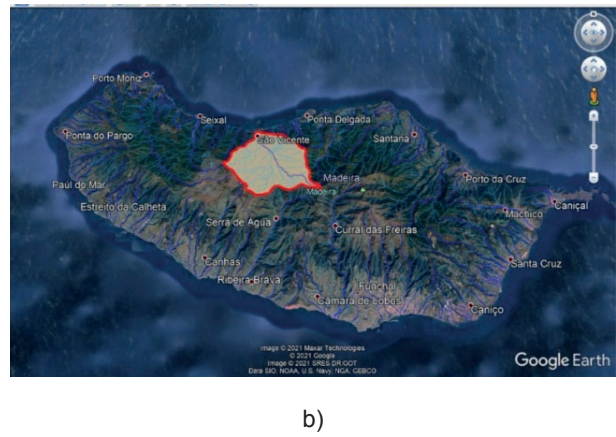
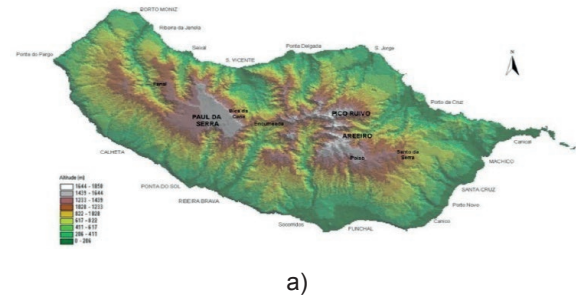


Figure 6: Madeira Island: (a) Topography and (b) Location of the São Vicente watershed.

3.1.1. Energy Goal for the Region

In 2011 targets were set by the Regional Government, under the Pact of Islands, to achieve 50% of production from renewable sources. Since climate change may condition the transport of fuel oil by sea, there is thus, in addition to the issue of sustainability, a great need for independence from fossil energies.

In order to improve the energy produced through renewable means, complementary support systems to the electricity generating system were adopted (e.g. pumping systems and battery plants associated with reversible hydroelectric systems and synchronous compensators) in order to take advantage of the renewable energy produced during hours of low consumption.

Currently most of the hydroelectric network is being used by the largest hydroelectric plants in the region, namely: Socorridos (SCR), Serra de Água (SDA), Calheta 1 (CTA1), Calheta 2 (CTA2), Calheta 3 (CTA3), Stream da Janela (RDJ) and Fajã da Nogueira (FDN) (Figure 7). The next strategy to reuse hydropower is, therefore, the implementation of mini-hydropower plants in the remaining streams.

3.1.2. Topographic Survey of the Stream of São Vicente County

Subsequently, a photogrammetric survey of the intervention area was carried out to produce a 3D model of the river and its surroundings. The three-dimensional model of the river was created using Bentley Systems’ Context Capture photogrammetry and 3D modelling software, and the equipment used to collect data for



Figure 7: Catchment areas (coloured spots) and respective hydroelectric power plants (pink lines).

subsequent processing of the photogrammetric model was a DJI Phantom 4 Pro drone and a Leica GS16 GPS (Figure 8).

First control points (photogrammetric points (PP)) were marked on the terrain and then georeferenced using a GPS (Figure 9). In the program, connections were made between the points captured in the photographs and the respective coordinates read by the GPS at the same points. Given the irregularity of the terrain and the weak GPS signal in the area, it was only possible to mark the



Figure 8: Photogrammetry equipment for data gathering.

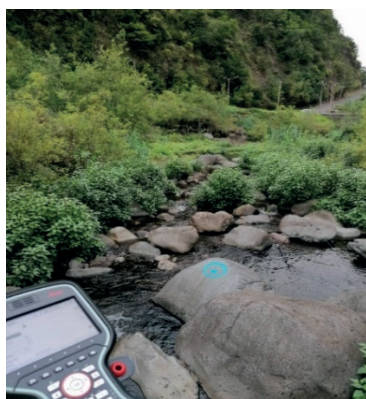


Figure 9: Photograph of a photogrammetric point after GPS reading, taken in Stream of São Vicente.

photogrammetric points along the road that accompanies the water stream. As the greater the number of points, the greater the accuracy of the model, in areas further away from the main water line there is less accuracy compared to reality. In total 104 PPs were marked along a 4 km length and about 2300 aerial photographs were taken, over 15 days of fieldwork.

After processing the photogrammetry part, it was possible to generate a terrain triangulation surface in order to export the data to a classic 2D format (Lundstrom et al., 2013). Using the contour lines extracted from the model, longitudinal profiles of the main and secondary watercourses were drawn.

3.2. Hydrological Data of the Municipal zone of São Vicente

Regarding the hydrological study of the Stream de São Vicente, the IPMA (Portuguese Institute of Sea and Atmosphere) was requested to the meteorological data collected in Madeira Island from 2011 to 2020. Besides the meteorological data, EEM (Madeira Electricity Company) provided several data regarding the hydrological network of the island and the company's hydroelectric operation network that allowed a more detailed hydrological study.

Hydrological monitoring is a widely employed method to understand the evolution mechanism of precipitation – flow variation in watersheds under various climate conditions. Hydrological monitoring systems can provide relevant information that can be utilized in small hydropower design, floods adaptation, early warning systems to mitigate risks by issuing early warnings. These monitoring systems can be significantly enhanced, and wider deployments can be achieved through the recent developments within the domain of the Internet of Things (IoT).

3.2.1. Watershed

The watershed of the steam of São Vicente presents in its whole 37.54 km², flows into the Atlantic Ocean and can reach 1690 m of altitude. However, in this case study only about 23.21 km² can be counted and reach maximum elevations around 1300 m. This reduction is due to the fact that part of the watershed drainage is being taken advantage of by the Socorridos hydroelectric power plant, situated in the County of Câmara de Lobos and the Serra de Água power plant, situated in the County da Stream Brava. For data simplification, this reduced basin was given the name of Useful Watershed.

It is possible to observe in the following image (Figure 10), that the zone in purple refers to the area drained to Socorridos, in green the part directed to Serra de Água and the red line the São Vicente basin limits. The remaining useful area of the basin is represented by the light blue colour.

3.2.2. Precipitation

The meteorological data provided by IPMA referred to all meteorological stations in Madeira Island. First a selection

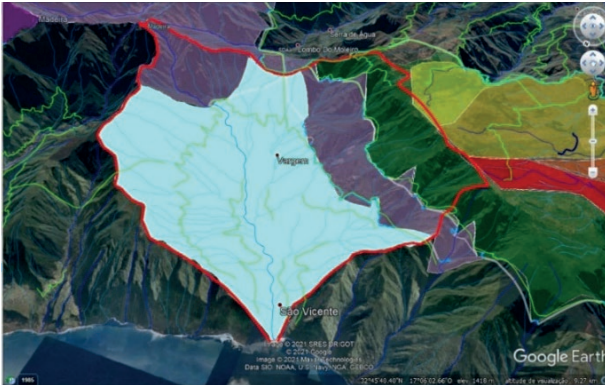


Figure 10: Colour representation of the area of influence on the other hydroelectric plants in the São Vicente basin.

of the stations close to the basin was made and then, through the Thiesen Polygon Method (method used to define the areas of influence of each station) the stations that would be used to obtain the monthly precipitation values were defined.

It was concluded that the ideal for this project would be the use of the Bica da Cana station, situated in a high area (1560 m) and the São Vicente station (97 m), resulting in a greater coverage and a more accurate estimate for obtaining the final values. Both stations became operational only in 2010, requiring data processing from the year 2011 to 2020. Table 1 shows characteristics of used rainfall stations.

The meteorological data provided by IPMA referred to all meteorological stations on the island of Madeira. Firstly, a selection of the stations close to the basin was made and then, using the Thiesen Polygon Method (method used to define the areas of influence of each station) the stations that would be used to obtain the monthly precipitation values were defined.

In the following image (Figure 11) it is possible to observe the application of the Thiesen Polygon Method. The shaded areas represent the areas of influence of each of the stations in the useful hydrographic basin, the pink zone being the area of influence of the São Vicente station (represents 86.2% of the useful basin) and the green zone the area of the Bica station da Cana (represents 13.8% of the useful basin).

The monthly precipitation data were then obtained through two meteorological stations of IPMA, the São Vicente station and the Bica da Cana station.

Subsequently, the average monthly rainfall was calculated, taking into account the weight of each of the

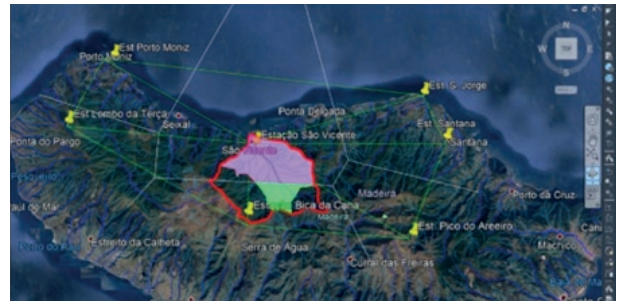


Figure 11: Computation of mean rainfall using Thiessen polygon method.

stations and, therefore, a series of monthly rainfall values was obtained over the 10 years under study (Figure 12).

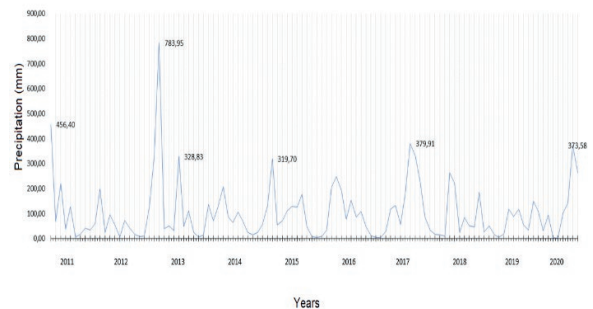


Figure 12: Average monthly precipitation of the catchment area.

3.2.3. Evapotranspiration

To calculate the evapotranspiration values for the useful basin, the Thornthwaite and Turc methods were used since the meteorological stations of Bica da Cana and São Vicente do not have installed evaporimeters. Figure 13 presents a main parameters and variables to compute evapotranspiration values.

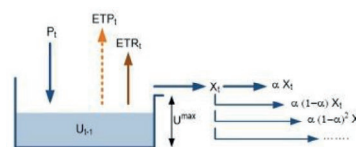


Figure 13: Representation of parameters and variables to compute evapotranspiration values.

Table 1: Geographic data of São Vicente and Bica da Cana rainfall stations.

Name	Latitude	Longitude	Altitude	County	Start of Operation
São Vicente	32.800283	17.044722	97	São Vicente	01/08/2010
Bica da Cana	32.756469	17.057689	1560	Ponta do Sol	01/08/2010

The formulation used for computation are presented as follows:

$$U_t^{av} = \begin{cases} \min \left[(ETP_t - P_t) \frac{U_{t-1}}{U^{max}}; U_{t-1} \right] & \text{if } P_t \leq ETP_t \\ \text{No need to compute} & \text{if } P_t > ETP_t \end{cases} \quad (8)$$

$$ETR_t = \begin{cases} ETP_t & \text{if } ETP_t \leq P_t + U_t^{av} \\ P_t + U_t^{disp} & \text{if } ETP_t > P_t + U_t^{av} \end{cases} \quad (9)$$

$$U_t = \begin{cases} U^{max} & \text{if } P_t - ETR_t > U^{max} - U_{t-1} \\ U_{t-1} + P_t - ETR_t & \text{if } P_t - ETR_t \leq U^{max} - U_{t-1} \end{cases} \quad (10)$$

$$X_t = P_t - ETR_t - (U_t - U_{t-1}) \quad (11)$$

where, U^{av} = water available in the soil for evapotranspiration, ETR = real evapotranspiration during a time step t , U = water available in the soil at time t , and X = excess water at time t (available for aquifer recharge and superficial runoff).

The original formulation of the Thorhthwaite Matter model assumes that the excess water X is evenly distributed between the current time period and the next time period.

On the other hand, in the absence of any information relating to flows, one can resort to formulas, necessarily approximate, such as Turc's formula (1954) (established on the basis of 254 river basins located in Europe, Africa, America and in Java and therefore with different climates).

$$\bar{P} = \bar{H} + \bar{E} \quad (12)$$

$$\text{if } \left(\frac{\bar{P}}{L_e} \right)^2 \geq 0.1 \rightarrow \bar{E} = \frac{\bar{P}}{\sqrt{0.9 + \left(\frac{\bar{P}}{L_e} \right)^2}} \quad (13)$$

$$\text{if } \left(\frac{\bar{P}}{L_e} \right)^2 < 0.1 \rightarrow \bar{E} = \bar{P} \quad (14)$$

and,

$$L_e = 300 + 25\bar{T} + 0.05\bar{T}^3 \quad (15)$$

where \bar{P} = average annual precipitation (mm), \bar{H} = average annual runoff (mm), \bar{E} = mean annual real evapotranspiration (mm), \bar{T} = average annual air temperature (°C), and L_e = evaporating power of the atmosphere (mm).

To estimate the average evapotranspiration value for the area under study, the weight of each of the stations calculated previously by the Thiessen method was taken into account. The Bica da Cana station therefore represents an incidence of 13.8% and the São Vicente station the remaining 86.2%. Figure 14 shows the annually average values of evapotranspiration using the aforementioned methods.

The evapotranspiration values for the Turc method are higher since this method takes into account not only temperature, but also, solar radiation and relative humidity, making the calculation more accurate.

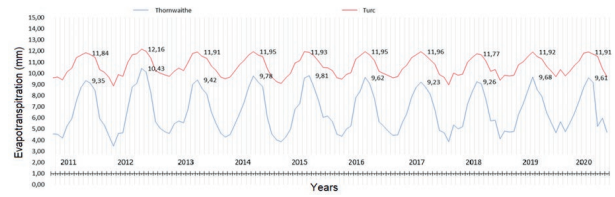


Figure 14: Monthly evapotranspiration.

3.2.4. Hydrological Balance

The runoff that occurs in the hydrographic network results from precipitation, hypodermic runoff and underground reserves. The volcanic origin of the island of Madeira led to the formation of subvertical voids and veins that together with its geological characteristics, namely the impermeable soils, allowed the natural creation of suspended aquifers at altitude.

The assessment of surface water availability on the island of Madeira presents great difficulty and considerable uncertainty due to the recognized scarcity of hydrological data, especially those relating to flow where the number of measuring points and the size of the periods of records are clearly insufficient. Such scarcity is all the more pertinent as there are additional factors, namely those related to the network of "levadas" (i.e., water canals) and underground circulation, which interfere in a significant and complex way with the surface manifestations of the flow and, consequently, make it difficult to interpret the occurring processes. In order to appreciate the general course of the hydrological series and to detect possible specificities of them, chronological diagrams of monthly precipitation and monthly runoff (expressed in water height) in the catchments of the six selected hydrometric stations were elaborated. The chronological diagrams obtained revealed the existence of frequent periods, especially in the summer semester (from April to September), with monthly runoffs that can exceed very significantly the precipitations in those months. For such occurrences it is admitted that the contribution of springs and subsurface runoff in each hydrographic basin may have special importance (Gaspar and Portela, 2002; Prada et al., 2005; Oliveira et al., 2011).

Hidden precipitation phenomena are particularly important in Madeira Island. Recent studies point to very significant condensation rates above level 900, especially in areas of Laurissilva, a fact that contributes to the regularization of the stream bed". For the Hydrologic balance, ML tool was applied based Precipitation, temperature and evapotranspiration estimations to get the following Figure 15.

Considering the shortage of daily flow data for São Vicente Watershed, the average annual mean daily flow duration curve was plotted considering the daily precipitation values and a regional analysis. The data collected from the two meteorological stations, ranging from the year 2011 to 2020, were treated. Afterwards, it was possible to calculate the modular flow. Dividing the values of the flows of the time series by the modular flow rate (Qmod), and the dimensionless curve is then obtained (see Figure 16).

IoT, machine learning and photogrammetry in small hydropower towards energy and digital transition: potential energy and viability analyses

Year	Month	P	tj	ij	Dj	Nj	fj	a	ETP	P-ETP	L	S	ETR	ETR<=ETP	Di	SH	R	R obs	MSE	R est	R obs	
		(mm)	ec	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(-)	(mm)	(mm)	OK ou NAO?	(mm)	(mm)	(mm)					
011/201	Out	95.7	16.6	6.15	31	0.96	0.99	1.58	64.0	31.7	0.0	0.0	64.0	OK	0.00	31.7	15.86	5.26	112	1	15.86	5.26
	Nov	83.5	12.9	4.20	30	0.83	0.83	1.58	36.0	47.5	0.0	47.5	36.0	OK	0.00	0.0	7.93	5.62	5	2	7.93	5.62
	Dez	129.6	10.8	3.21	31	0.81	0.84	1.58	27.4	102.2	0.0	149.7	27.4	OK	0.00	0.0	3.96	12.23	68	3	3.96	12.23
	Jan	236.5	9.6	2.68	31	0.84	0.87	1.58	23.6	212.9	0.0	300.0	23.6	OK	0.00	62.6	33.26	59.13	669	4	33.26	59.13
	Fev	171.3	10.9	3.25	28	0.83	0.77	1.58	25.8	145.5	0.0	300.0	25.8	OK	0.00	145.5	89.40	74.74	215	5	89.40	74.74
	Mar	67.8	12.6	4.05	31	1.03	1.06	1.58	44.5	23.3	0.0	300.0	44.5	OK	0.00	23.3	56.37	22.98	1115	6	56.37	22.98
	Abr	61.0	13.9	4.70	30	1.11	1.11	1.58	54.1	6.9	0.0	300.0	54.1	OK	0.00	6.9	31.62	16.33	234	7	31.62	16.33
	Mai	66.6	16.2	5.93	31	1.24	1.28	1.58	79.5	-12.9	-12.9	287.3	79.3	OK	0.27	0.0	15.81	17.57	3	8	15.81	17.57
	Jun	141.2	19.4	7.79	30	1.25	1.25	1.58	103.1	38.1	0.0	300.0	103.1	OK	0.00	25.5	20.65	19.35	2	9	20.65	19.35
	Jul	1.8	21.6	9.16	31	1.27	1.31	1.58	128.2	-126.4	-126.4	196.9	104.9	OK	23.24	0.0	10.32	6.11	18	10	10.32	6.11
	Ago	0.0	21.5	9.10	31	1.18	1.22	1.58	118.2	-118.2	-244.6	87.1	109.8	OK	8.45	0.0	5.16	2.82	5	11	5.16	2.82
	Set	5.4	20.2	8.28	30	1.04	1.04	1.58	91.4	-86.0	-330.5	29.0	63.6	OK	27.81	0.0	2.58	3.47	1	12	2.58	3.47
Valores Anuais /		1060.4		68.5				795.7		-714.4	2297.5	735.9		59.77	295.5	292.94		2448	13	1.29	3.47	
Ano	Mês	P	tj	ij	Dj	Nj	fj	a	ETP	P-ETP	L	S	ETR	ETR<=ETP	Di	SH	R	Escoamento Observado (mm)	MSE	R est	R obs	
		(mm)	ec	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(-)	(mm)	(mm)	OK ou KO?	(mm)	(mm)	(mm)					
012/201	Out	17.9	16.6	6.15	31	0.96	0.99	1.58	64.0	-46.1	-376.6	8.2	38.6	OK	25.38	0.0	1.29	3.47	5	16	0.16	31.98
	Nov	145.6	12.9	4.20	30	0.83	0.83	1.58	36.0	109.6	0.0	117.9	36.0	OK	0.00	0.0	0.65	4.17	12	17	0.08	43.97
	Dez	36.3	10.8	3.21	31	0.81	0.84	1.58	27.4	8.9	0.0	126.7	27.4	OK	0.00	0.0	0.32	8.68	70	18	52.69	16.81
	Jan	87.3	9.6	2.68	31	0.84	0.87	1.58	23.6	63.7	0.0	190.4	23.6	OK	0.00	0.0	0.16	31.98	1012	19	26.34	12.51
	Fev	116.1	10.9	3.25	28	0.83	0.77	1.58	25.8	90.3	0.0	280.8	25.8	OK	0.00	0.0	0.08	43.97	1926	20	21.01	9.92
	Mar	169.0	12.6	0.00	31	1.03	1.06	1.58	44.5	124.5	0.0	300.0	44.5	OK	0.00	105.3	52.69	16.81	1287	21	10.50	9.68
	Abr	6.8	13.9	4.70	30	1.11	1.11	1.58	54.1	-47.3	-47.3	256.2	50.6	OK	3.54	0.0	26.34	12.51	191	22	5.25	3.06
	Mai	16.1	16.2	5.93	31	1.24	1.28	1.58	79.5	-63.4	-110.8	177.1	95.2	KO	-15.67	15.7	21.01	9.92	123	23	2.63	1.41
	Jun	9.4	19.4	7.79	30	1.25	1.25	1.58	103.1	-93.7	-204.4	89.6	96.9	OK	6.15	0.0	10.50	9.68	1	24	1.31	2.11
	Jul	0.1	21.6	9.16	31	1.27	1.31	1.58	128.2	-128.1	-332.5	29.6	60.1	OK	68.03	0.0	5.25	3.06	5	25	0.66	1.68
	Ago	0.0	21.5	9.10	31	1.18	1.22	1.58	118.2	-118.2	-450.7	6.6	23.0	OK	95.21	0.0	2.63	1.41	1	26	0.33	2.73
	Set	24.6	20.2	8.28	30	1.04	1.04	1.58	91.4	-66.8	-517.5	1.2	30.0	OK	61.37	0.0	1.31	2.11	1	27	0.16	5.13

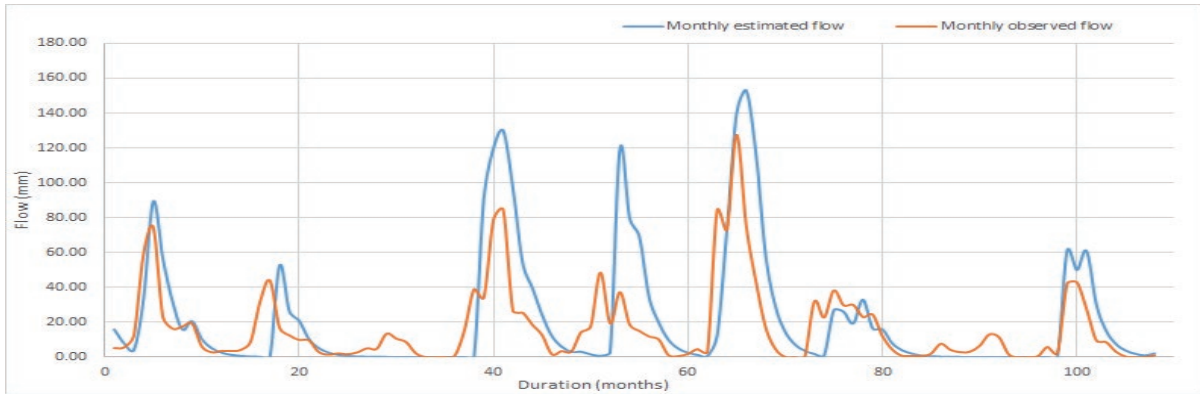


Figure 15: Estimation of monthly flow by the technique of hydrologic balance: example of ML input data (a); Application of the balance model (b).

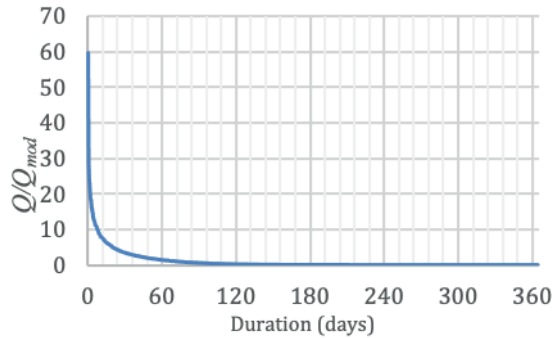


Figure 16: São Vicente watershed dimensionless curve.

Using the maps of average annual isolines of surface runoff, subsurface and hypodermal runoff and total runoff, it was possible to define the runoff that best fits the São Vicente area (Figure 17) (Gaspar and Portela, 2002). The runoff value chosen was 900 mm. Subsequently a Qmod was calculated for the basin, this being equal to 662.39 l/s.

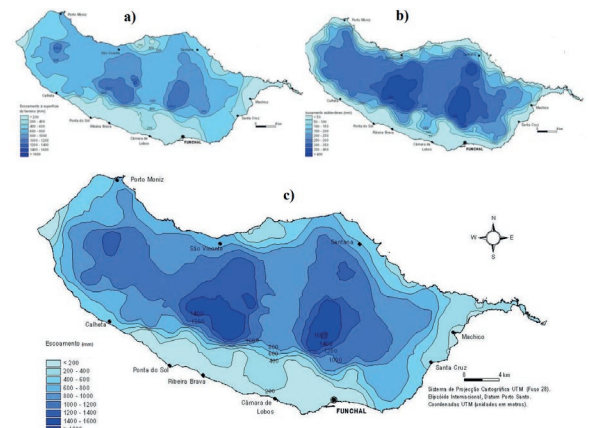


Figure 17: Mean annual isolines of: a) runoff at the land surface (mm); b) subsurface and hypodermic runoff (mm) and c) total runoff (mm).

Once the modular flow rate for the basin under study has been estimated, this value is multiplied by the dimensionless curve, obtaining the curve of average annual duration of the average daily flow rate for the São Vicente watershed (Figure 18).

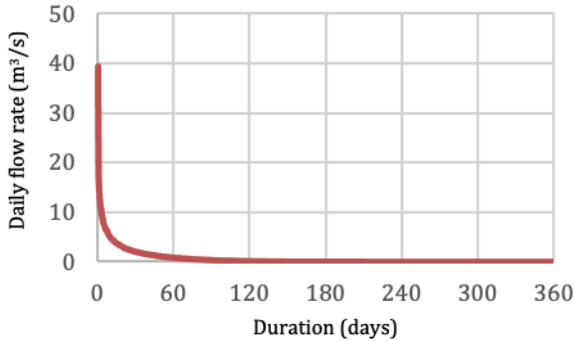


Figure 18: Curve of the average annual daily flow of the São Vicente Watershed.

A subtraction of 5% of the (Qmod) value was considered in order to account for the water retained in the streams that is later used by human action as irrigation flow and a further subtraction of 5% of the (Qmod) value to guarantee the ecological flow of the stream at all times.

In order to confirm on site, the values obtained by the hydrological study, it was decided to carry out field tests to compare these values with the flow estimated by the hydrological balance.

Two visits to the site were made during the month of September and a third one during the month of August. A section with easy access and regular geometry was chosen, close to the area where the weir will be built, for greater accuracy of results. Through the use of measuring equipment (surveying rod, aluminium ruler and measuring tape), it was possible to trace a cross-sectional profile of the section in question and the wetted perimeter (Figure 19).

To calculate the flow velocity, the distance travelled between two markers is measured and the time taken for a float to travel through the central zone of the section is timed (Figure 20). In summary, three field tests were carried out at each site visit (Table 2).

The friction between the free surface and the air and the resistance offered by the walls and the bottom, cause different velocity distributions along the channel cross-section. In this case study, the friction between the free surface and the air was neglected since the chosen section was very close to an acceleration zone. In order to

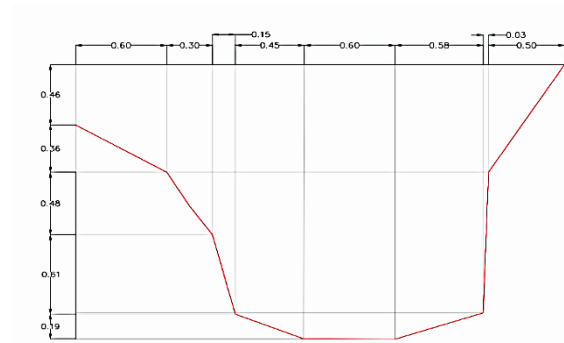


Figure 19: Cross-section profile of the test site in the Stream de São Vicente.



Figure 20: Test site at Stream de São Vicente.

consider the critical situation, a correction factor (0.8) was applied to the velocity value measured in the superficial layers.

After discussing the results in situ tests, and comparing them with the values of the hydrological balance, the design flow rate of 200 l/s was considered.

3.3. Sizing of the small-hydro

Small “run of the river” projects do not have a conventional dam with a reservoir, only a weir to form a head pond for diversion of inlet water to the turbine. The first step in the design of the mini-hydropower plant consisted in defining the catchment location and the implantation site that would guarantee sufficient hydraulic load, but also, that it would be possible to catch the largest flow available <https://www.irena.org/publications/2019/May/Tracking-SDG7-The-Energy-Progress-Report-2019>; Stojkovic

Table 2: Data collected in situ for sampling.

Tests	Average time (s)	Control Distance (m)	Velocity (m/s)	Section (m ²)	Q (l/s)
20/09/2021	8.35	1	0.1198	1.12	134.13
15/10/2021	7.47	1	0.1339	1.55	207.5
27/10/2021	6.02	1	0.1661	2.19	363.79
Average					235.14

et al., 2017)). To do so, the longitudinal profile was analysed and the area was defined to guarantee that the upstream had the largest possible number of secondary watercourses flowing into the main stream. We then used the GIS model made by the Context Capture program (Figure 21) for a better perception of the chosen area and to survey the elevation of the site (Sechin, 2014; Suziedelyté-Visockiené et al, 2015).

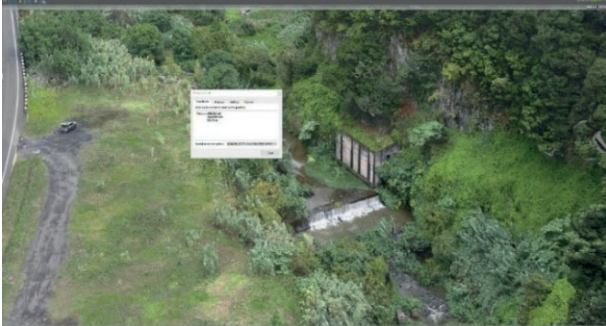


Figure 21: Representation of the weir site (Context Capture Viewer via IoT).

The second step was to choose the site for the power station/turbine. Through the model the site that presented the best conditions was chosen (Figure 22), without compromising local houses or public roads, besides guaranteeing easy and safe access. The course of the supply channel was also traced from the intake point to the area considered for the implementation of the loading chamber (Figure 22 and 23). Thus, the length of the supply channel will be 1890 m. Considering a continuous gradient of 0.5% between the intake level and the turbine's implementation level, it was possible to estimate a gradient of 76 m.

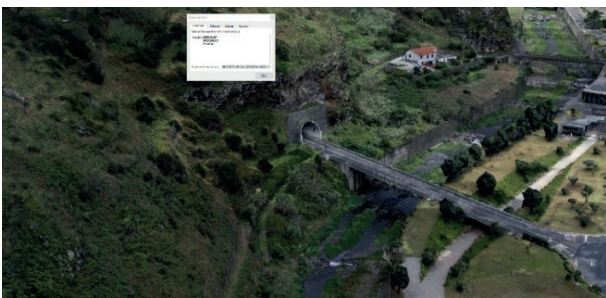


Figure 22: Representation of the location of the power plant (Context Capture Viewer via IoT).

After defining the implantation sites and the design of the conveyance channel, the third and last step consisted in the dimensioning of the main elements that constitute a small hydroelectric exploitation. To this end, the fundamentals were applied to the design of a small hydropower plant.

The first step in sizing the dam is to obtain the discharge flow for a given flood return period. In an ideal situation, the calculation would be carried out for a period of T=100 years, but no meteorological data were found for that zone over such a long period.

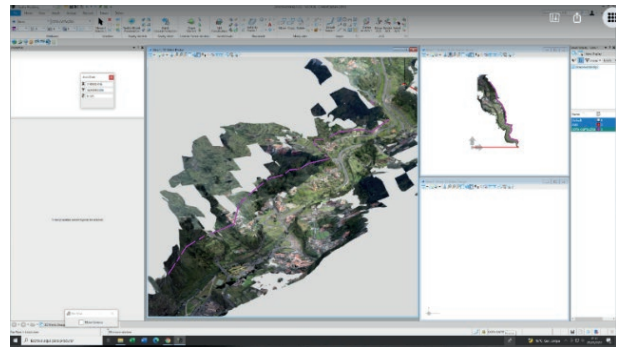


Figure 23: Representation of the course of the supply channel from the capture zone (Context Capture Editor).

For the calculation of the intensity of precipitation Oliveira et al. (2011), therefore, the data collected and processed after the alluvium that reached the island on February 20, 2010 were considered (Figure 24). On the North slope, the high areas of São Vicente and Boaventura were the zones where it rained with greater intensity. So, the value of intensity was considered the maximum precipitation value felt in this zone during the period of one hour being adopted 60 mm/h.

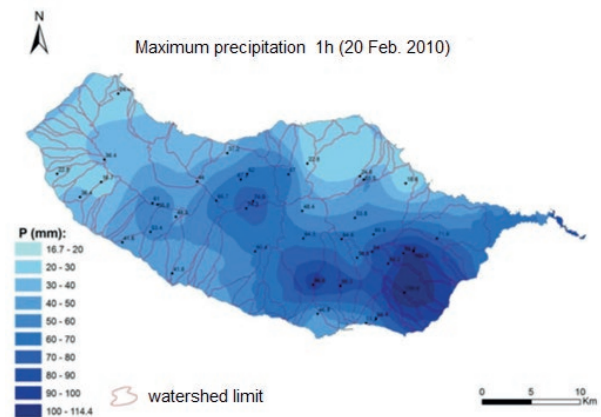


Figure 24: Maximum hourly precipitation.

Regarding the area of the basin, the entire area of the São Vicente basin was taken into account for safety reasons, which corresponds to the value of 37.54 km². The coefficient (C) must present values in the order of 0.8, so that the estimates of peak flood flows are adequate. The flood flow was obtained, being Q = 493 m³/s. Consequently, to define the value of weir length (L), the 3D model initially created was used to extract the width of the stream in the chosen area for the construction of the small dam (or weir).

Fine particles can settle in a settling basin, which can wear out parts of the turbine and reduce its efficiency and lifespan. Settling occurs due to gravity reducing the flow velocity by increasing the cross-section of the settling basin (Figure 25). These basins are usually prismatic basins where the flow is mainly horizontal. The sedimentation basin can be divided into four zones: (i) inlet zone, (ii) settling zone, (iii) discharge zone, and (iv) sludge storage zone.

The inlet zone should ensure uniform distribution of flow velocity by directing the flow through a perforated baffle plate. The settling zone allows sedimentation of solid particles. Clean water is discharged into the hydraulic conveying system through an outlet weir or orifice.

For design purposes, the solid particles are assumed to be spherical and of uniform specific gravity. The typical dimensions of the settling basin (or a desludging basin) for an inflow discharge Q (200 l/s) at the inlet of the basin with a depth D (1 m), a width W (1.3 m) and a length L (6 m) (Ramos, 2000).

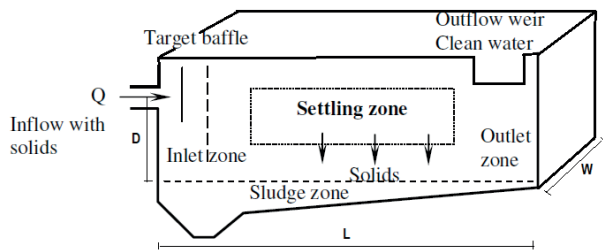


Figure 25: Sedimentation basin.

For each basin cross section, the flow at the free surface is assumed to be horizontal and of uniform velocity. The particles tend to settle to the bottom with a falling velocity ($V_s = 0.15$ m/s). Normally, the mean diameter of the particles (D_{50}) considered acceptable for small turbines is about 0.2 mm. This value depends on each turbine type (the turbine manufacturer should indicate the maximum allowable particle dimension).

Main factors that influence the basin behaviour are the flow turbulence and the non-uniform horizontal velocity distribution. One way to obviate this problem consists in increasing the superficial area, A_s , of the basin or the width (W) and removing all angles or unnecessary singularities. The width and the flow velocity must be controlled in order to avoid the lift up of settling particles (i.e., verification of the non-drag criterion).

Regarding the penstock, the pipe diameter was first defined with 400 mm for a speed of 1.6 m/s. After defining the diameter, the head losses associated with the hydraulic circuit were calculated (Quaranta and Revelli, 2015)

For the calculation of local head losses, two 45° flanged elbows, two transitions, with valves, the passage through the grate and the entry into the conduit were considered. A 3D model based on IoT and GIS was used to calculate the distance of the penstock (L_p). Finally, the useful head value of the system was calculated, subtracting the calculated head losses from the available head, resulting a net head of 66.14 m.

After calculating the values of flow and available hydraulic head, the most appropriate choice of turbine for the case study is made. The defined values were the following: water flow of 200 l/s and a head of 64.14 m.

Through the analysis and using the IoT of the database of several manufacturers, it is possible to conclude that the turbine that best suits the specific conditions of the terrain is a Pelton turbine, as shown in Figure 26.

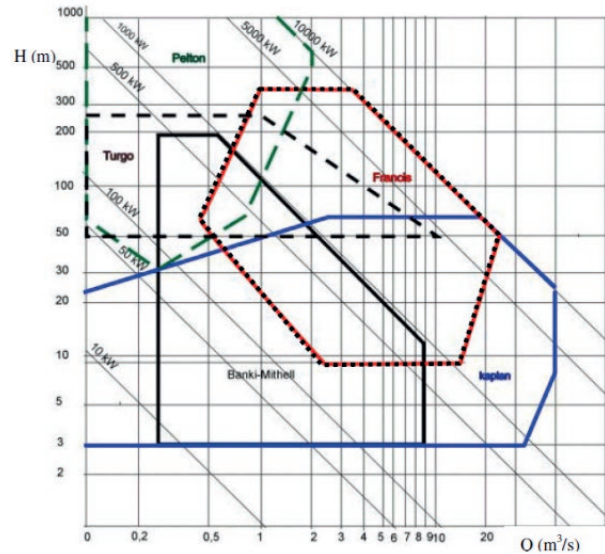


Figure 26: Turbine range application.

Establishing an efficiency of 85%, for the turbine to be applied on site, it gives rise to a power of 106.85 kW. The sizing values are represented in following Table 3:

Table 3: Turbine characteristics.

Item	Value
η (-)	0.85
P (kW)	106.86

The Internet of Things (IoT) proved to suite of sharply connected devices that moved data over a network of different equipment of measurement, interpretation and calculation. IoT data looks a lot like any other data that are running over a system, but putting together different platforms and protocols. IoT looks as instrumental at last to-end joining of different specialty units and procedures that prompts better coordination between survey, data collected, and design. Analyses, and business elements to improve its functionalities. IoT integration platform, with its key features, has been its ability that offers accuracy and visibility over significant engineering business-extensive procedures.

Furthermore, it is using the available information for incorporation, assemble data from different sources according to design prerequisites with innovative solutions. IoT systems assume a straightforward job to upgrade the attributes of enormous information comprising speed, volume, and assortment. IoT integration data and results make use of different components consisting of incessant sensors that unendingly gather large measures of intelligence, exponentially more noteworthy data.

4. Economic Analysis

4.1. Justificative Framework

This viability study includes an analysis of the costs and the financial and ecological benefits generated, for

a useful life of 20 years, the period associated with the maintenance of the equipment.

Once the dimensions of the entire project had been defined, the concrete volume and excavation volume for each of the hydraulic circuit components were calculated. Market consultations were made in order to carry out a price study for each of the civil construction works associated with the project components (see Figure 27).

For some components additional costs were considered to account for locksmith's work. Accessories, finishes, among others, although the concrete prices already include formwork, casting and steel placement and labour.

The exploration and functioning costs during the useful life were taken into account, as well as the benefit for the reduction of CO₂ gas emissions.

Subsequently, the investment evaluation indicators were applied in order to assess the entire profitability of the project. After the assessment of its profitability, it is possible to conclude whether the project under study is of interest to investors.

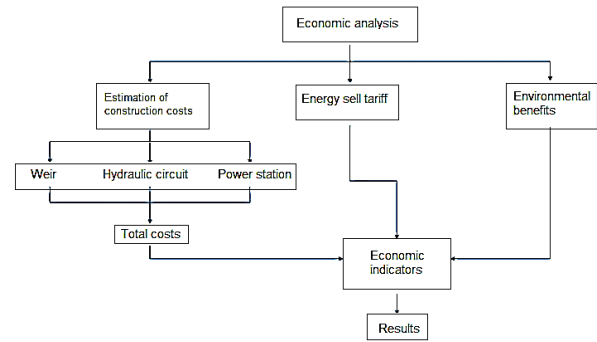


Figure 27: Scheme of economic analysis.

4.2. Estimated Construction Costs

The estimated construction cost for the project were computed as presented from Table 4 for the weir, supply channel, sedimentation basin, transition channel, penstock, and hydropower plant (Ramos, 2000; Kumar et al., 2020; Santolin et al., 2011).

Table 4: Unit and total costs associated with the construction of the dimensioned weir, supply channel, sedimentation basin, transition channel, penstock and hydropower plant.

Item	Units	Quantities	Unit Price (€)	Total Price (€)
Concrete Volume	m ³	302.50	375.00	113,437.50
Excavation Volume	m ³	185.35	5.00	926.75
Various	-	1.00	10,000.00	10,000.00
Weir cost				124,364.25
Item	Units	Quantities	Unit Price (€)	Total Price (€)
Concrete Volume	m ³	196.35	375.00	73,631.25
Excavation Volume	m ³	1,103.94	5.00	5,519.70
Buried Pipe	ml	500.00	12.86	6,430.00
Various	-	1.00	350,000.00	350,000.00
Supply channel				435,580.95
Item	Units	Quantities	Unit Price (€)	Total Price (€)
Concrete Volume	m ³	5.41	375.00	2028.75
Excavation Volume	m ³	32.00	7.00	224.00
Various	-	1.00	15000.00	15,000.00
Sedimentation				17,252.75
Item	Units	Quantities	Unit Price (€)	Total Price (€)
Concrete Volume	m ³	0.58	375.00	216.00
Various	-	1.00	2000.00	2,000.00
Transition chan.				2,216.00
Item	Units	Quantities	Unit Price (€)	Total Price (€)
Concrete Volume	m ³	8.00	375.00	3,000.00
Excavation Volume	m ³	2044.80	7.00	14,313.60
Pipe	ml	75.00	220.00	16,500.00
Accessories	-	1.00	20,000.00	20,000.00
Various	-	1.00	10,000.00	10,000.00
Penstock				63,813.60
Item	Units	Quantities	Unit Price (€)	Total Price (€)
Civil Construction	-	1.00	63,071.33	6,3071.33
Equipment	-	1.00	159,213.99	159,213.99
Power station				222,285.32

The cost of the building site was 8% of the total value of the contract. 69,241.03€. The total cost is 934,753.90€.

4.3. Energy Selling Price

The energy sales values are shown in Table 5.

Table 5: Energy sales values of EEM BTN for one day.

Item	Pu/kwh	Hours	Total Price (kW/day)
Tip	0.29 €	5	1.46 €
Full	0.15 €	9	1.39 €
Void	0.08 €	10	0.83 €
			3.68 €

Therefore, the Energy Production over a year can be estimated. Being the value of 106.85 kWh, the energy cost 3.68 euros kWh/day and considering that the turbine will operates 305 days per year, being only stopped during two summer months, the value of Annual Energy Production is 119,928.44 €.

4.4. Environmental Benefits of CO₂ Reduction

Although the economic analysis is fundamental to the project's viability study, other parameters should also be taken into consideration. Some of the main benefits that this project would bring are, mostly, from the environmental point of view, along with its social impact. In fact, the promotion and visibility, of the project are essential factors for the use of renewable energy and encourage new similar projects.

Taking into account that the energy produced in this project has a renewable origin, it was considered a benefit for reduction of CO₂ emissions. The production of mini-hydro would symbolize a reduction of about 1815 tCO₂ per year, with the price of 52.07 €/tCO₂e. which would represent a benefit of 94,515.97 €/year. This benefit will be accounted as a revenue.

The social impact assesses the effects based on economic, technical, cultural, institutional and environmental factors, causing a positive change in citizens. It is clear that the reduction of equivalent CO₂ emissions into the atmosphere, in addition to the revenue generated by renewable electricity generation, both induce social benefits. The use of renewable energies, promotes and spreads the green culture and generates satisfaction among citizens. It can serve as inspiration for other similar projects, public or private, that can contribute to a more environmentally friendly electricity consumption. One of the biggest social impacts would be the creation of jobs. Namely in project development, construction, operation, exploitation and maintenance.

Using the 3D model of the Stream de São Vicente, it was possible to choose the best routes and locations for the hydraulic structures, without generating negative social impacts and facilitating access for maintenance.

4.5. Economic Balance

Operating costs were considered to be 0.5% of the initial investment, 5,107.79 €. and maintenance, conservation and administrative/operating costs represent 7% of the annual revenue, 14,951.30 €, totalling 20,059.09 €/year.

It was decided to perform 3 simulations with different discount rates of 8%, 10% and 12%. For the 3 discount rates, at the end of the useful life considered, the economic indicators obtained are all positive, as shown in Table 6.

Table 6: Values of BCR, NPV and PRI obtained for the different upgrade rates for the sized hydropower plant.

I (%)	8%	10%	12%
NPV	878,556.05 €	626,078.79 €	424,009.28 €
BCR	1.86	1.63	1.42
PRI	7 years	7 years	9 years

Taking the discount rate of 12%:

- The Benefit-Cost Ratio (BCR) value is 1.42, which is greater than 1;
- The Net Present Value (NPV) obtained indicates that during the established horizon, it is not only possible to recover the initial investment, but it is also possible to obtain a net benefit of 424,009.28 €;
- The Period of Return on Investment (PRI) is 7-9 years, being quite positive for the dimensions of the project with an installed power of around 107kW.
- The Internal Rate of Return (IRR) value is 18.30%, being higher than all the discount rates, which represents that the investment achieves a capital income higher than the average costs of these capitals.

Based on all the project and assumptions developed in this study, it is concluded that the project is economically viable, from the point of view of the company that explores, produces and commercializes the energy in Madeira, the EEM, and that it can give a significant contribution for the energetic transition, even more relevant facing what is happening in Europe.

5. Final Considerations

This type of sustainable project is increasingly urgent in the context of the circular economy and energy transition. On one hand it is the use of an available resource and on other hand the renewable energy production and smart tools and equipment. In particular, as this project is located in a place that is isolated and dependent on air and sea transport, the independence from fossil fuels and the capacity for energy production, with an estimated power of 107 kW, from renewable energy source, has become imperative.

The solution proposed, despite presenting a considerable building cost, in face of the project components, will allow the production of a clean energy through the water that would be "lost" and it flows daily in one of the biggest riversides of Madeira Island, benefiting the populations that live in contiguous areas, in what concerns water-energy

nexus. The use of new tools such as IoT, photogrammetry and ML allowed to improve the project, reduced the time of estimations, evaluations, surveys and definition, in 80% in time, and at the same time was possible to ensure reliability and optimization of the final solution. This result will imply a reduction of CO₂ emissions that are annually released into the atmosphere, of the order of 1800 tCO₂, making the small hydro socially and ecologically viable and very well accepted.

The economic analysis concluded that it is viable and of interest to the Autonomous Region of Madeira (RAM), if the suggested solution or a similar one goes ahead, serving as a pilot project for most of remaining streams in Madeira Island. This will allow opening doors to new implementations of small hydropower plants in the region using digital tools which can improve the final solution. This research study will be a source of inspiration for other sustainable public or private projects in the water sector, which may contribute to a more environmentally-friendly electricity consumption towards energy transitions to better face the climate change effects.

ML and IoT, together with Geographic Information Systems and photogrammetry used in the development of this research were fundamental at all stages of the research in terms of project development, surveys and decision supports systems, design evaluation in a shorter time. It

should be noted that for future work on the design and feasibility studies of hydropower plants, these systems must be exploited and their analysis and design improved in the estimation of fundamental parameters for both components of the hydrological study, the characterisation of the best technological solution to be adopted, sizing and costs estimation of all system elements.

The photogrammetric survey carried out allowed a better interpretation of the site and an easier decision making, saving time and resources, with measurements to be supported in situ using IoT, that could be swapped with a higher level of confidence. These types of technological solutions interconnected, using batteries, are especially essential in more remote locations, where there is no hydrologic enough collected data with reliability and adequate sample size, as demonstrated in case study.

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