Decision Support System for Solar Energy Adoption

Carlos Lopes, Diogo Martino, Nuno Bandeira, Fernando Almeida
1 Polytechnic Institute of Gaya, V.N.Gaia, Portugal,
2 University of Porto & INESC TEC, Porto, Portugal,

1 ispg4355@ispgaya.pt, 1 ispg4191@ispgaya.pt, 1 ispg4335@ispgaya.pt, 2 almd@fe.up.pt

Abstract - A decision support system (DSS) is a computerized information system that combines models and data to solve unstructured or semi-structured problems with intense user involvement. DSSs have high applicability in several business areas and enable users without technical knowledge in computing to manipulate the information needed for a more assertive decision-making process. This study presents a DSS to support the decision process of installing a photovoltaic solution that considers the contracted power, the monthly expenses in electricity, and the location of the installation. The return on investment is estimated considering the annual savings in electricity and the return on investment. The findings indicate the relevance of the application to support the user in choosing the best solution and reveal that geographical location is a determining factor in the potential energy savings. Furthermore, the payback period decreases by increasing users’ monthly consumption and is also potentiated by the increase in contracted power.

Keywords - decision-making process, investment return, photovoltaic panels, renewable energy, solar radiation, sustainability.

I. INTRODUCTION

The limited lifetime of fossil fuels and the consequences of their adoption (e.g. global warming, climate change, and security risks) are driving a change in the global energy landscape. Following this change, new government policies in support of renewable energy to replace fossil fuels have emerged. This solution, of natural and virtually inexhaustible source, has the potential to fully replace electricity generation in the most diverse areas (e.g. home, business, and transportation) traditionally generated from fossil fuels. According to Peterson et al. [1], this approach enables a secure transaction for a low carbon economy. Furthermore, Greiner et al. [2] point out that renewable energy, being endogenous, can lead to a decrease of energy from abroad.

Forecasts point to strong worldwide growth in electricity generation from renewable energy sources. According to the International Energy Agency (IEA), renewable energy capacity is expected to expand by approximately 50% between 2019 and 2024. Photovoltaic will be the main driver of this growth accounting for almost 60% of the expected growth in this period [3].

Photovoltaic systems are based on panels or modules composed of photovoltaic cells. These devices capture the energy of sunlight and produce electrical power. This current produced by photovoltaic modules is collected and processed by electronic inverters, which allow consumers to reduce electricity costs and become totally or partially independent in electrical energy [4].

Self-production electricity systems based on photovoltaic systems are very advantageous in light of rising electricity tariff inflation. Jordan and Kurtz [5] note that a home or business, by installing a photovoltaic system, are immune to increases in energy prices and guarantees the supply of electricity for a period of 25 to 30 years, which is the minimum estimated lifetime of a photovoltaic system. Therefore, the investment that the citizen makes in this system is paid back in a few years with the produced energy.

Grid-connected photovoltaic systems supply electricity to the consumer from the grid. All electricity produced by this means can be used for own consumption. When there is sunlight, the consumer can fully use his own electrical energy. In periods when there is no sunlight, the consumer continues to be supplied normally by the public electricity grid. Finally, in periods when consumption is low, surplus energy can
occur. In this case, the consumer can export energy to the public grid, becoming an electricity generator.

McAtee [6] and Yadav and Bajpai [7] consider that the growth in the efficiency levels of photovoltaic panels and the reduction of their costs, combined with the demand for clean energy that ensures energy sustainability, has made consumers increasingly look to solar energy as an energy alternative within their reach. Nevertheless, many consumers, especially those with less technical knowledge in the area of renewable energy, have difficulties in estimating the profitability of these investments. Several questions arise, including: How much will one be able to save? What is the ideal level of panels? What kind of photovoltaic cell material should we one choose? When will we one be able to recover the investment made? In this sense, and to help the consumer in taking this decision, a decision support system (DSS) has been developed that enables the user to simulate energy savings according to their level of consumption, type of installed photovoltaic panels, and geographical location of their home or business.

This study is structured as follows: first, a literature review is carried out on the process structure of a DSS and its application to planning and energy consumption. Next, the methodology of the study is outlined and the process of building the DSS is defined, considering its requirements and architecture. After that, the results of the study are presented regarding two scenarios (i.e., Porto and Beja). Finally, the main conclusions are enumerated, and the relevance and limitations of this study are explored.

II. LITERATURE REVIEW

A. The Concept of a DSS

Making good decisions is rarely an easy task. The concept of decision making is involved in a problem-solving process in which the decision-maker will set his/her preferences. Arnott and Pervan [8] point out that several elements can make the decision-making processes difficult, such as uncertainty, complexity, multiple goals, and different points of view.

A DSS is a subclass of an information system that helps the decision-maker to make better use of his/her knowledge and enable the generation of new knowledge. A DSS combines models and data to solve semi-structured problems and some unstructured problems, with intense user involvement [8]. A DSS is necessarily an interactive process that requires stakeholder dialogue [9]. Carton et al. [10] refer to a DSS as an organized set of people, procedures, software, databases, and devices used to help make decisions that solve problems. Consequently, the main emphasis of a DSS should be on improving the effectiveness of the decision process rather than seeking operational efficiency.

DSS came from various disciplines such as operational research, management, accounting, applied mathematics, databases, and artificial intelligence. Through the use of a DSS, it is expected to obtain useful and relevant information that enables decisions to be made, to give advice on the correct action to be taken and to monitor the decisions made through a simulation process that enables the consequences of the actions taken to be measured [11]. Furthermore, Chung et al. [12] refer to the usefulness of a DSS to store and manage knowledge, thus overcoming human limitations to information processing.

DSS has several characteristics, such as [11; 13]: (i) dealing with large volumes of data from different sources; (ii) supporting analysis and exploring data in detail; (iii) performing a complex and comparative analysis between various alternatives; (iv) supporting both optimizing and heuristic approaches; (v) performing analysis simulation; and (vi) presenting information flexibly and using both textual and graphical elements. A DSS has generically three main components [14]: (i) database management system, which allows decision-makers to perform an analysis of the vast data stored in an external database or repository; (ii) model base, which allows exploring the relationship between internal and external data; and (iii) user interface, which allows users to interact with the DSS to obtain information.

Finally, Table I performs a comparative analysis between the typical features of an information system vs. DSS. In short, the main difference between an information system and a DSS is the high flexibility and adaptability that the latter presents in the face of the changes that occur, not only in the focus of the problem but also in the context in which the problem is embedded.

B. DSS for Energy Consumption and Planning

In the field of energy planning, several studies aggregate data at national and regional levels for the establishment of public policies. Banerjee et al. [16] present a DSS that uses a geographic information
system and enables the optimization of regional energy network planning sustained in four levels: household, village, block, and district. A more recent study, and in this case based on clean energies, was conducted by Hettinga et al. [17], which aims to facilitate neighborhood energy planning. In this DSS, the process has to be initiated by a local authority with the involvement of multiple stakeholders with different perspectives, which contributes to the achievement of climate targets pre-defined by a municipality.

Another area of strong application of DSS is its adoption in the planning of smart cities. According to Eremia et al. [18], connectivity, responsible use of resources and autonomy are to be the main investments of smart cities. The diffusion of the smart grid concept requires original solutions where the inclusion of renewable energies in telecommunications, controls and new devices will have to be massive. DSS can play an important role in this field by making the services offered more efficient and enabling customers to be more participatory in their energy consumption. The study performed by Papastamatiou et al. [19] presents a DSS for smart cities to significantly reduce CO2 emissions. The approach of this study is based on two pillars: (i) assessment that allows identifying sectors with low energy performance; and (ii) optimization, which includes a proposal of specific action plans that can be used by the decision-makers of a city. Another study was also applied to smart cities, but in this case focus on the energy management of building consumption is presented by Stamatescu et al. [20]. In this study, a DSS is proposed, where renewable energy sources (e.g. wind turbine, photovoltaic panels) and a procedural decision algorithm are adopted to a microgrid.

Table 1. INFORMATION SYSTEMS VS. DSS (adapted from Marakas and O’Brien [15]).

| Feature                        | Information System                                      | Decision Support System                                      |
|--------------------------------|---------------------------------------------------------|-------------------------------------------------------------|
| Decision support type          | Provides information about the organization's performance. | Provides information and decision support techniques for problem analysis or identification of specific opportunities. |
| Frequency and form of the      | Regular and specific answers and reports.                | Interactive queries and answers.                             |
| information provided           |                                                         |                                                             |
| Information format             | Pre-defined and fixed.                                   | Adaptable and flexible.                                    |
| Information processing         | Information produced by extraction and manipulation of corporate data. | Information produced by analytical modeling of business data. |
| methodology                    |                                                         |                                                             |

III. METHODOLOGY

A. Research Design

The aim of this study is to propose a DSS that allows consumers less familiar with solar energy to estimate the return on investment they can obtain from the installation of photovoltaic panels considering multiple perspectives, namely the initial investment, type of panels, and the weather conditions of the installation site. In carrying out this study, a multiphase approach was considered to model the problem at an early stage and, after that, build a functional prototype and test its applicability in different contexts. Fig. 1 shows the structure of the research. The first phase is fundamental to conduct a literature review in the field of decision support systems, with a focus on their application to the planning and control of renewable energy systems. Next, the problem is modeled considering the approach defined by Sharda et al. [13], in which it becomes fundamental to use analytical models, which implement the "what-if" approach, to explore semi-structured and unstructured problems.

Still, during the preliminary phase of the study, a specification of the functional and non-functional requirements of the prototype is performed and its logical and physical architecture is defined. The last phase of the preliminary stage is responsible for the design of the scenarios that will assess the potential impact of this prototype in a productive environment.

The second phase of the research design is the fieldwork stage. In this phase, the prototype was developed using a waterfall methodology. According to Mohamed and Darwish [25], this software development model works sequentially, as the next step is performed after the previous one is completed. For this model to work properly all project requirements must be well defined. For this study, the waterfall model works correctly because in the preliminary stage the prototype requirements are already specified. After the development of the prototype is completed, acceptance tests are performed. These tests aim to verify if the software is ready to be used by users and all functionalities are...
fully implemented. The approach of performing formal acceptance tests as suggested by Cangussu et al. [26] was followed, in which when the prototype was specified the test cases were also defined, with the indication of the inputs, outputs, and process of performing the acceptance tests.

The last phase is the evaluative stage. In this phase, the previously defined scenarios have been executed and their results collected. These results were analyzed using the SPSS V.21 software. Then, the findings were discussed considering the context of each scenario and the existing literature on the subject. Finally, the findings were identified and summarized. Also, in the conclusions, it was possible to draw summary conclusions about the theoretical and practical impact of this study.

**B. Modeling**

In problem modeling, potential elements that have an impact on the choice of the photovoltaic equipment to be installed in a house or company were considered. The first element is the available area in the house/company (total surface, $t_s$) to install the photovoltaic equipment. Equation (1) shows that the area occupied by the panels (total panel area, $t_{pa}$) results from the size of each panel (individual panel area, $i_{pa}$) and has to be equal or less than $t_s$.

$$t_{pa} = \sum_{k=1}^{n} i_{pa} \leq t_s$$

Another restriction of the model is the energy costs of that location (energy costs, $ec$). Accordingly, the researchers have defined equation (2):

$$t_s \leq ec$$

Another restriction of the model is the weather conditions. However, unlike the other two restrictions that are deterministic and could be easily calculated through line optimization, atmospheric conditions are probabilistic depending on each geographic location and random factors. To estimate the atmospheric conditions, namely the solar radiation ($sr$) of a given location based on its latitude and longitude. Information from the last 10 years was collected to allow an inferential estimation of solar radiation over several months of the year. A significance level of 5% (i.e., $Z_{0.95}$) was adopted in

![Research phases and dependencies](image-url)
the estimation process of this interval, as established in equation (3):

\[
sr = sr(i) \pm Z_{0.95} \times \frac{\sigma}{\sqrt{n}}
\]  

(3)

This approach is distinct from machine learning techniques that seek to identify patterns in data and pursue continuous improvement of processes [28]. Moreover, these solutions are characterized as requiring a high computational load [29]. In this solution, the challenge is less since the data regarding the weather conditions are stable and verifiable, being only used to estimate the weather conditions of that location in the next years. In this sense, the use of inferential statistics through confidence intervals is an easy and fast approach that allows the researchers to meet the challenges of the problem.

After the restrictions were identified, the objective of the problem was represented, which consists of simultaneously maximizing the \(I_S\) and minimizing the payback period of the investment. These two objectives may, in some cases, be contradictory, because a solution that obtains high savings may necessarily have too high an initial investment and only obtain a return for too long a period. In this sense, and as Arnott and Pervan [8] state, the DSS should have a broad dialogue with the user and allow these decisions to be made by the decision-maker. In this sense, the prototype developed does not seek to replace the decision-maker, but only to give him/her more information on the potential and limitations of each proposed solution.

The existence of probabilistic elements in the problem modeling made this study represent the problem through a decision tree. Decision trees are diagrams capable of enumerating all logical possibilities of a sequence of uncertain decisions and occurrences [30]. They show schematically the whole set of alternative actions and possible events throughout a project. When it is possible to know the probabilities associated with each branch, then the expected value of a decision can be calculated. The representation of the problem in this study according to a decision tree is done in Fig. 2.

In this scheme, and for simplification purposes, only two solutions are represented. Based on the weather forecast \((wf)\) performed for the user location, the expected value \((ev)\) is calculated according to the solar radiation probability \((p)\).

**C. Functional and Non-functional Requirements**

According to Hamad et al. [31], it is relevant to organize requirements considering their importance for end-users. The objective is to prioritize the implementation of the requirements starting with those with a higher degree of importance. Furthermore, it becomes relevant to distinguish between functional and non-functional requirements. Sommerville [32] considers the behavior of a system towards the client's business process as a functional requirement, while everything concerning the general characteristics of a system (e.g., cost, usability, performance, safety, etc.) are non-functional requirements. Table II presents the functional and non-functional requirements considered in the implementation of this project. The priority of requirements has been defined according to the stakeholders of the project which includes the business sector and public agencies.

**D. Physical and Logical Architecture**

The application was developed in C# and uses the Net Framework V4.8. SQL Server is the DBMS used to store the application data (e.g., simulations, equipment, and users). This choice, based on Microsoft technologies, facilitates communication between the two technologies and allows optimizing the performance of connections with the database [33]. Fig. 3 presents the physical architecture of the application. The communication between the client and the server is performed through TCP/IP. The SQL Server database is stored on the server-side.

The logical architecture is in turn useful for understanding the structure and organization of the system design. It can also be used to describe the workflows between the functionalities implemented in the application. Fig. 4 presents the logical architecture of the application. The access to the application by the user is done through the "login" component. From this component, it is possible to register a new user or access the main menu. Another central component in
logical architecture is the "simulation" component. After performing a simulation, the user interacts with the "dashboard" and "export simulation" components. These two components are responsible for showing the simulation results and exporting them to an external application (if desired by the user).

| Feature                        | Priority     | Description                                                                 |
|--------------------------------|--------------|-----------------------------------------------------------------------------|
| Register in the application    | High priority| A user must log in to the application to be able to use it later.            |
| Authentication in the application | High priority| Only an authenticated user can run a new simulation.                         |
| Dashboard drawing              | High priority| Customized statistical table for each user where information on the simulations performed can be accessed. |
| Import weather conditions      | Moderate priority| The weather information is obtained from the Power by Nasa API providing the user's latitude and longitude. The monthly average of solar radiation considering the last 10 years is calculated. |
| Export results                 | Low priority | The simulation results can be exported to JSON and CSV.                     |
| Access to history              | Low priority | The user must see all performed simulations on the platform, and if desired, export them to a file. To access this requirement, the user needs to have at least one simulation completed. |

### Functional and Non-Functional Requirements

#### Functional requirements

- **Register in the application**: High priority - A user must log in to the application to be able to use it later.
- **Authentication in the application**: High priority - Only an authenticated user can run a new simulation.
- **Dashboard drawing**: High priority - Customized statistical table for each user where information on the simulations performed can be accessed.
- **Import weather conditions**: Moderate priority - The weather information is obtained from the Power by Nasa API providing the user's latitude and longitude. The monthly average of solar radiation considering the last 10 years is calculated.
- **Export results**: Low priority - The simulation results can be exported to JSON and CSV.
- **Access to history**: Low priority - The user must see all performed simulations on the platform, and if desired, export them to a file. To access this requirement, the user needs to have at least one simulation completed.

#### Non-functional requirements

- **Usability**: High priority - Navigation in the application should be concise and user-friendly to let the user easily access all functionalities.
- **Security**: High priority - The data stored by the application must be backed up daily and must comply with the rules established by the General Data Protection Regulation (EU GDPR).
- **Reliability**: High priority - The application must provide an actual and accurate simulation. The user must have a reliable source of information to make precise decisions.
- **Performance**: Moderate priority - The information disclosed to the user from the simulation process shall have a response time fewer than 3 seconds. Furthermore, the navigation on the dashboard must have an immediate response time.
- **Interoperability**: Moderate priority - The application must be able to communicate with external APIs and store the data in a Database Management System (DBMS).
- **Scalability**: Low priority - The development of the program should follow a modular structure to facilitate the inclusion of new features without breaking the entire project.

### E. Prototype

Technology products must be used by a wide range of people. Furthermore, Rusu et al. [34] consider that design has a close relationship with user satisfaction, so it is important to build an application in which its features are easily identifiable by a new user. Therefore, the concept of user experience (UX) emerges, which is an element responsible for gaining and retaining user loyalty [35]. Consequently, the application presents a simplistic design to be used by any type of user to cover a larger number of people.

The application provides a traditional authentication system based on the email and password model. The access credentials are unique for each user. The password is encrypted in the database using SHA-3. The application also provides a registration system for new users. The dashboard is displayed after a successfully authentication (Fig. 5). The dashboard shows the version of the installed application, the number of simulations performed and the number of panels available in the database. From the dashboard, it is possible to perform a new simulation or see the history of performed simulations.

The key functionality offered by the application is the realization of new simulations. Fig. 6 shows the process of running a new simulation. Three groups of data are requested from the user: (i) property details; (ii) power details; and (iii) financial details. The indication of the location of the user's house/company is done by requesting the zip code or enabling the location to be found by georeferencing. Information on consumption data is then requested, namely the total bill, % of the energy used during the night, price per kwh, average consumption, and the use of batteries. Finally, the user has to specify his/her budget and the importance given to the quality of the panels, batteries, and inverters.
Fig. 3. Physical architecture.

Fig. 4. Logical architecture.

Fig. 5. Dashboard.
After a simulation is performed, its results are made available considering several analysis parameters, as shown in Fig. 7. The user is provided with information on the types of panels, batteries, and inverters to be purchased. Furthermore, information is provided on the efficiency of the panel. The following information is provided as financial indicators of return on investment: (i) annual savings; (ii) payback period; and (iii) system cost. Moreover, relevant technical information like the number of panels and monthly production in kWh is also made available. Finally, and since profitability estimated over one year is not deterministic, a graph is made available indicating the worst and best case considering the weather conditions at the installation.
site. The findings of each simulation can be exported to JSON and CSV.

IV. RESULTS AND DISCUSSION

The application was tested in Portugal considering two geographical environments with specific particularities. The city of Porto (latitude = 41.1496 and longitude = -8.6110) is located in the North of Portugal, has an average elevation of 89.53 meters and an annual average of solar radiation of 3.93 kw-hr/m²/day. The city of Beja (latitude = 38.0151 and longitude = -7.8632) is located in the South of Portugal, has an average elevation of 189.94 meters and an annual average of solar radiation of 4.57 kw-hr/m²/day. For each geographic region, two independent variables were defined: (i) contracted power; and (ii) total bill. As dependent variables they were considered: (i) system cost (SC); (ii) panel number (PN); (iii) minimal and maximum annual savings (MN/MX); and (iv) payback period (PP). The number of photovoltaic panels considered ranged from 2 to 5. There were no restrictions regarding the weight and size of the photovoltaic panels.

A. City of Porto

Table III presents the simulation results for the city of Porto. Several levels of contracted power (from 3.45kw to 17.25kw) and monthly expenses (from 30 to 180 euros) were considered in the energy bill. For each scenario, SC, PN, MN, MX, and PP were calculated. The number of panels required and, consequently, the initial investment grows as energy consumption increases. On the opposite, the period of return on investment decreases as monthly consumption increases. This information confirms the data obtained by studies [36-37], in which it is concluded that the payback period of investments in solar photovoltaic is correlated with the consumption pattern. The increase in contracted power is another factor that also shortens the payback period of the investment. This occurs because this is a fixed amount paid on the energy bill and, consequently, the use of solar energy will decrease the need of energy consumption from an energy supplier. Thornhill [38] considers that despite the instability in energy prices and the investment made by energy distribution companies in renewable energy, investment in photovoltaic panels remains profitable, even if the process of selling energy to the public grid entails higher upcoming costs for the citizen.

B. City of Beja

Table IV presents the simulation results for the city of Beja. The findings obtained for Beja are similar to those obtained for Porto. The found oscillations result from different weather conditions between the two both cities. This situation causes a decrease in the recovery time of the investment. For example, considering a contracted power of 3.45kw and a monthly expenditure of 30 euros, we have there is a reduction of 0.8 years in the recovery period of the investment between the two both cities. However, this reduction is not uniform and low to 0.5 years for a contracted power of 17.25kw and a monthly expenditure of 180 euros. The impact of geographical location on the profitability of a photovoltaic energy project is also mentioned by Castillo et al. [39]. In this study, the regional potential for solar power generation in EU-28 is measured: (i) south of Portugal; (ii) south of Spain; and southeast of Italy. When the researchers combined the results obtained by Castillo et al. [37] and this study, they found that Beja is located in an area of high potential for solar energy investments, while the city of Porto is in an area with moderate potential. In this sense, the results obtained in this study are consistent with the solar energy potential offered by these two cities.

C. Comparative Analysis

Fig. 8 shows the evolution of the return of investment in years (y axis) considering the monthly expenses in euros (x axis). It allows us the researchers to compare the recovery rate of the investment considering three scenarios for each city. SN1 considers a contracted power equal to 3.45kw, while in SN2 the value is 10.35kw and for SN3 it is 17.25kw. Regardless of the contracted power, the value of the return on investment in a city with a high potential for solar power generation is higher than in a city with moderate potential. The evolution of PP follows a decreasing logarithm function, with higher variability in PP for relatively low monthly energy expenses. For higher values of energy consumption, the maximum limit imposed in the simulation of five solar panels becomes insufficient to make the investment in the same proportion profitable. The developed application enables users to indirectly define the maximum number of panels by indicating their budget. Considering that the potential user of this application is an ordinary citizen without specific knowledge in the field of photovoltaic panels, it was decided to define a maximum limit in the user’s budget.
### Table 3. SIMULATION FOR THE CITY OF PORTO.

| Contracted power (kw) | SC=1243€ | SC=2683€ | SC=2683€ | SC=2683€ | SC=2683€ | SC=2683€ |
|-----------------------|----------|----------|----------|----------|----------|----------|
| 3.45                  | PN=2     | PN=5     | PN=5     | PN=5     | PN=5     | PN=5     |
| MN=107€               | MN=256€  | MN=296€  | MN=316€  | MN=331€  | MN=346€  | MN=346€  |
| MX=143€               | MX=340€  | MX=395€  | MX=422€  | MX=442€  | MX=461€  | MX=461€  |
| PP=9.9y               | PP=9y    | PP=7.8y  | PP=7.3y  | PP=6.9y  | PP=6.6y  | PP=6.6y  |

| 6.9                   | SC=1243€ | SC=2203€ | SC=2683€ | SC=2683€ | SC=2683€ | SC=2683€ |
|-----------------------|----------|----------|----------|----------|----------|----------|
| PN=2                  | PN=4     | PN=5     | PN=5     | PN=5     | PN=5     | PN=5     |
| MN=112€               | MN=226€  | MN=302€  | MN=326€  | MN=341€  | MN=356€  | MN=356€  |
| MX=150€               | MX=302€  | MX=402€  | MX=435€  | MX=455€  | MX=474€  | MX=474€  |
| PP=9.5y               | PP=8.3y  | PP=7.6y  | PP=7.1y  | PP=6.7y  | PP=6.5y  | PP=6.5y  |

| 10.35                 | SC=1243€ | SC=2203€ | SC=2683€ | SC=2683€ | SC=2683€ | SC=2683€ |
|-----------------------|----------|----------|----------|----------|----------|----------|
| PN=2                  | PN=4     | PN=5     | PN=5     | PN=5     | PN=5     | PN=5     |
| MN=112€               | MN=226€  | MN=302€  | MN=326€  | MN=341€  | MN=356€  | MN=356€  |
| MX=150€               | MX=302€  | MX=402€  | MX=435€  | MX=455€  | MX=474€  | MX=474€  |
| PP=9.5y               | PP=8.3y  | PP=7.6y  | PP=7.1y  | PP=6.7y  | PP=6.5y  | PP=6.5y  |

| 13.8                  | SC=1243€ | SC=2203€ | SC=2683€ | SC=2683€ | SC=2683€ | SC=2683€ |
|-----------------------|----------|----------|----------|----------|----------|----------|
| PN=2                  | PN=4     | PN=5     | PN=5     | PN=5     | PN=5     | PN=5     |
| MN=114€               | MN=229€  | MN=305€  | MN=329€  | MN=344€  | MN=359€  | MN=359€  |
| MX=152€               | MX=306€  | MX=407€  | MX=439€  | MX=459€  | MX=479€  | MX=479€  |
| PP=9.3y               | PP=8.2y  | PP=7.5y  | PP=7.1y  | PP=6.7y  | PP=6.4y  | PP=6.4y  |

| 17.25                 | SC=1243€ | SC=2203€ | SC=2683€ | SC=2683€ | SC=2683€ | SC=2683€ |
|-----------------------|----------|----------|----------|----------|----------|----------|
| PN=2                  | PN=4     | PN=5     | PN=5     | PN=5     | PN=5     | PN=5     |
| MN=115€               | MN=232€  | MN=309€  | MN=332€  | MN=347€  | MN=362€  | MN=362€  |
| MX=154€               | MX=309€  | MX=411€  | MX=443€  | MX=462€  | MX=481€  | MX=481€  |
| PP=9.2y               | PP=8.1y  | PP=7.5y  | PP=6.9y  | PP=6.6y  | PP=6.4y  | PP=6.4y  |

**Fig. 8.** Analysis of the payback period between Porto and Beja.
Table 4. SIMULATION FOR THE CITY OF BEJA.

| Contracted power (kw) | Monthly expenses (€) |
|-----------------------|-----------------------|
|                       | 30                    | 60                    | 90                    | 120                   | 150                   | 180                   |
|                       | SC=1243€              | SC=2203€              | SC=2683€              | SC=2683€              | SC=2683€              | SC=2683€              |
|                       | PN=2                  | PN=4                  | PN=5                  | PN=5                  | PN=5                  | PN=5                  |
|                       | MN=117€               | MN=235€               | MN=316€               | MN=346€               | MN=360€               | MN=375€               |
|                       | MX=156€               | MX=313€               | MX=421€               | MX=461€               | MX=481€               | MX=500€               |
|                       | PP=9.1y               | PP=8y                 | PP=7.3y               | PP=6.6y               | PP=6.4y               | PP=6.1y               |
| 3.45                  |                       |                       |                       |                       |                       |                       |
|                       | SC=1243€              | SC=2203€              | SC=2683€              | SC=2683€              | SC=2683€              | SC=2683€              |
|                       | PN=2                  | PN=4                  | PN=5                  | PN=5                  | PN=5                  | PN=5                  |
|                       | MN=119€               | MN=240€               | MN=323€               | MN=355€               | MN=371€               | MN=386€               |
|                       | MX=159€               | MX=320€               | MX=430€               | MX=473€               | MX=495€               | MX=515€               |
|                       | PP=8.9y               | PP=7.9y               | PP=7.1y               | PP=6.5y               | PP=6.2y               | PP=6y                 |
| 6.9                   |                       |                       |                       |                       |                       |                       |
|                       | SC=1243€              | SC=2203€              | SC=2683€              | SC=2683€              | SC=2683€              | SC=2683€              |
|                       | PN=2                  | PN=4                  | PN=5                  | PN=5                  | PN=5                  | PN=5                  |
|                       | MN=120€               | MN=242€               | MN=325€               | MN=356€               | MN=371€               | MN=386€               |
|                       | MX=160€               | MX=322€               | MX=433€               | MX=474€               | MX=495€               | MX=515€               |
|                       | PP=8.9y               | PP=7.9y               | PP=7.1y               | PP=6.5y               | PP=6.2y               | PP=6y                 |
| 10.35                 |                       |                       |                       |                       |                       |                       |
|                       | SC=1243€              | SC=2203€              | SC=2683€              | SC=2683€              | SC=2683€              | SC=2683€              |
|                       | PN=2                  | PN=4                  | PN=5                  | PN=5                  | PN=5                  | PN=5                  |
|                       | MN=122€               | MN=246€               | MN=330€               | MN=360€               | MN=374€               | MN=389€               |
|                       | MX=163€               | MX=328€               | MX=439€               | MX=480€               | MX=499€               | MX=519€               |
|                       | PP=8.7y               | PP=7.7y               | PP=7.6y               | PP=6.4y               | PP=6.1y               | PP=5.9y               |
| 13.8                  |                       |                       |                       |                       |                       |                       |
|                       | SC=1243€              | SC=2203€              | SC=2683€              | SC=2683€              | SC=2683€              | SC=2683€              |
|                       | PN=2                  | PN=4                  | PN=5                  | PN=5                  | PN=5                  | PN=5                  |
|                       | MN=124€               | MN=249€               | MN=333€               | MN=363€               | MN=379€               | MN=393€               |
|                       | MX=165€               | MX=332€               | MX=445€               | MX=484€               | MX=504€               | MX=524€               |
|                       | PP=8.6y               | PP=7.6y               | PP=6.9y               | PP=6.3y               | PP=6.1y               | PP=5.9y               |
| 17.25                 |                       |                       |                       |                       |                       |                       |

V. CONCLUSION

Solar photovoltaic panels enable the production of clean and renewable energy and, at the same time, contribute to reducing the ecological footprint and the electricity bill. Generating free and clean electricity during the day will allow citizens to cover part of their energy needs at home or in their business. By having this extra source of electricity, consumption during the day will amortize the need for grid energy use. Furthermore, savings on the electricity bill can be increased by the existence of batteries that can accumulate the surplus produced. Moreover, it is also feasible to have financial return with the generation of electricity from the sun, because depending on the production, the surplus that is injected into the grid can be paid by the electricity supply company.

This study proposed the development of a DSS to support the decision process of a photovoltaic installation supporting it in defining the installed capacity and estimating the return on investment. With this, it is intended to have a solution with a relevant impact on the environmental and financial perspectives, and it contributes to the sustainable development of cities. Using the application, the user can indicate his budget limit and, based on this information, estimate the annual savings on the electricity bill. Furthermore, the application considers the location of the user, hence the return on investment is also determined based on this information.

The obtained results considered the use of this DSS by users in two Portuguese cities (i.e. Porto and Beja). These cities are in two distinct areas of potential for solar power generation. The findings indicate that geographical location is a determining factor in energy savings and the period of return on investment decreases as monthly consumption increases. Furthermore, the decrease in this period of return on investment is greater for high values of contracted power.

This study offers essentially practical contributions by providing a DSS for decision support in solar migration.
using photovoltaic panels. This DSS is flexible by allowing proposed solutions to be parameterized according to the contracted power, monthly energy bill and geographical location of the installation. This study also presents several limitations that should be highlighted. Firstly, only one type of panel was considered and only the purchase price of the panel was registered. Next, the dashboard is still relatively basic, there being no saving indicators considering other alternative solutions. Finally, the tests carried out considered only two cities in Portugal and it is recommended that more tests can be carried out considering other geographical areas in the EU. As future work, we the researchers intend to automate the process of collecting information from photovoltaic panels, considering several types of solar panels like polycrystalline, monocrystalline, or with advanced efficiency solar modules. Furthermore, the dashboard should be redesigned to ensure that the information provided is more relevant to the user, namely indicating for each solution several alternatives and comparing the return on investment offered by them.

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