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TOWARDS A SUSTAINABILITY ASSESSMENT FRAMEWORK FOR FLOATING PHOTOVOLTAIC SYSTEMS IN CITIES

GIACOMO GIOVANNI LUCA TESTORI

1948636

g.g.l.testori@student.utwente.nl

Supervisors:

- Dr. E.J. Aukes
- Dr. F.H.J.M. Coenen

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SETs: Solar Energy Technologies

PV: Photovoltaic

SDGs: Sustainable Development Goals

DHS: District Heating System

MFC: Multifunctional Centre Camminghastins

HDPE: High-Density Polyethylene

ABSTRACT

Solar energy is the most promising renewable source to promote a sustainable energy transition in cities. Floating photovoltaic (PV) solar panels have recently been applied over inland water bodies to gain advantages in terms of efficiency, economics, and land use. As a matter of fact, applying solar panels above water increases the energy performance, which in turn decreases the payback time of the installation. In addition, floating panels do not require any land, which is a valuable commodity in places characterized by high population density and limited land, like in cities. Nevertheless, floating PV systems have never been installed in an urban environment, meaning that it is not known whether they can promote sustainable energy development in cities. To acquire this knowledge, a sustainability assessment must be carried out, but such a process has never been implemented for floating PV systems. This research project aims to answer the question: *How can the sustainability of a floating PV system in an urban neighbourhood be assessed using a decision-support framework and specific methodologies?* To tackle this question, this paper develops a new state-of-the-art decision-support framework for assessing the sustainability of floating PV systems in urban areas. Such a framework is presented as a step-by-step conceptual model that consists of three development stages (Planning, Construction, Operation & Decommission) which in turn are distributed across the following six steps. (i) Selecting and specifying a suitable location and (ii) the system's components, (iii) defining goals sought to be achieved, (iv) identifying sustainability indicators, and (v) evaluating them to generate data and information necessary for the (vi) assessment. Such an assessment tool includes the specific methodologies necessary to carry out each step of the framework. To test the validity of this framework, this document presents its application on a fictional energy project where a floating PV plant is planned to be implemented in an urban neighbourhood in Leeuwarden, The Netherlands. The results of the fictional energy project suggest that the framework and the methodologies are valuable tools to carry out the sustainability assessment of floating PVs. In addition, the study identifies limitations in some of the methodologies proposed (such as the use of a basic 3-D modelling software rather than a professional solar energy analysis software) and explains possible improvements. In conclusion, it is reasonable to say that the structure of this conceptual model is a valid resource to implement the framework in future energy projects. Furthermore, some of the methodologies used should be further enhanced to propose a preliminary instrument for the development of a universally recognized framework to assess the sustainability of floating PVs in cities.

1. INTRODUCTION

1.1 BACKGROUND

Cities around the world consume 80% of the global energy demand and generate 65% of the total CO_2 emissions (Habitat, 2011). Therefore, achieving sustainable energy development in urban areas is an essential goal for the future of world society (Steg, Werff, & Perlaviciute, 2015). The installation of solar energy technologies (SETs) in cities is the best approach to reduce their environmental footprint and generate sustainable and CO_2-free energy (Droege, 2008). Photovoltaic (PV) solar power generation is one of the most accessible and eco-friendly products among SETs. Its utilization is growing rapidly due to technological improvement, scalability of the system, cost reduction in materials, and policymaking support (Byrne, Taminiau, Seo, Lee, & Shin, 2017). Nevertheless, even the sustainability of PV solar systems in the built environment cannot be taken for granted (Byrne, Taminiau, Seo, Lee, & Shin, 2017). In fact, the implementation of PV technologies in cities faces sustainability problems related to technical and environmental challenges and social and economic barriers. The most common issues are finding a suitable location, choosing the system's components, the average low efficiency of PV modules, i.e., 15-20% of incident sunlight is converted into electricity, social acceptance, and high installation costs. Furthermore, solar PV panels have the burden of intense land requirements (Hernandez, Hoffacker, Murphy-Mariscal, & Wu, 2015).

Floating PV systems have recently been applied on inland water bodies to gain advantages in terms of efficiency, economic performance, and land use (Acharya & Devraj, 2019). These features make floating solar technologies an attractive innovation for future PV systems, especially in places where land use becomes a valuable commodity and electricity demand is increasing, like in most cities around the world (Byrne, Taminiau, Seo, Lee, & Shin, 2017). Although they have been deployed on large- and medium-scale projects i.e., Bomhofsplas floating solar plant in Zwolle, the Netherlands (Figure 1), no valuable research has been done on floating PV systems installed in an urban context, like on a canal of a residential neighbourhood (Acharya & Devraj, 2019). Consequently, even though floating PVs are more efficient and economic than traditional panels and do not require any land, it is not known whether this type of system can be implemented on urban water bodies and promote sustainable energy development (Fiksel, Eason, & Frederickson, 2012). As a matter of fact, floating PVs cannot just be installed in any water body, but there are several factors to be considered. Matters like finding a suitable location, choosing the right components, the environmental impact on the ecosystem, and social acceptance remain major issues to be considered when installing floating PV technologies, especially in inhabited districts (Afgan, Carvalho, & Hovanov, 2000). To know whether floating PVs can be beneficial in an urban area, their sustainability must be assessed, meaning that the technical, economic, environmental, and social dimensions of the system must be evaluated (Shau, Yadav, & Sudhakar, 2016).

Figure 1: Floating PV system in Bomhofsplas, Zwolle, sized 27 MWp (BayWa, 2020).

1.2 RESEARCH TOPIC

A sustainability assessment is one of the most recent and recognized decision-support tools to implement the concept of sustainable energy development in cities (Stankovic, Dzunic, Dzunic, & Marinkovic, 2018). Such an appraisal method is based on a framework that guides engineers to identifying and assessing the technical, economic, environmental, and social aspects and impacts that an energy system has in a geographical area during its lifetime (Stankovic, Dzunic, Dzunic, & Marinkovic, 2018). The efficacy of this methodology is being progressively recognized by engineers, especially in the early development stages of new energy projects. Indeed, when applied prior to installation, a sustainability assessment can be used as a tool to prospectively determine the advantages and disadvantages of a power plant and decide whether it should be implemented or not in a specific location. Consequently, it can help engineers to predict the aspects and impacts that an energy system would have on an area before installation so that planning related matters, i.e., finding a suitable location and choosing the system's components, and the impacts of the construction and operation & decommission activities become part of an integrated and prospective evaluation (Santoyo-Castelazo & Azapagic, 2014). Therefore, a sustainability assessment can be used to predict the aspects and impacts of a floating PV system in a neighbourhood of a city and determine whether such a system can promote sustainable energy development in an urban environment.

1.3 PROBLEM STATEMENT

A sustainability assessment is translated into actions through a decision-support framework that guides engineers to evaluate a real-life energy project (Fiksel, Eason, & Frederickson, 2012). Nevertheless, a limited number of studies have issued a state-of-the-art decision-support tool to carry out an integrated sustainability assessment of a power plant before installation. Besides, the existing frameworks do not consider the technical, environmental, economic, and social dimensions together, meaning that their evaluation is not completed and can lead to unreliable decision-making strategies. Also, it is not clear how a sustainability assessment can predict the aspects and impacts of an energy system for the development stages of an energy project, i.e., planning, construction, operation & decommission. Consequently, as of now, there is not a universally recognized framework that can guide engineers to predict the advantages and disadvantages of an energy system prior to installation. In addition, the application of a sustainability assessment changes in accordance with the energy system that is being evaluated. In fact, precise evaluation methods are necessary for the assessment of a specific energy system. Nevertheless, these methods have rarely been considered in integrated research, especially for floating PV technologies. As a result, to assess the sustainability of floating PVs in an urban context, it is necessary to develop a state-of-the-art decision-support framework to guide engineers in predicting the technical, social, economic, and environmental aspects and impacts of such an energy system in a location. Once a state-of-the-art framework is established, it must be further designed by defining the specific evaluation methods needed for the assessment of floating PV technologies. These methods must provide a logical and systematic approach to enable the selection of a suitable location and the right components, and the analysis of the technical, social, economic, and environmental aspects and impacts of an urban floating PV system.

1.4 RESEARCH OBJECTIVE

This research project aims to develop a state-of-the-art decision-support framework that guides engineers to carry out a sustainability assessment of an urban floating PV system prior to installation. The framework will include specific methodologies to analyse in advance the suitability of a location and the system's components and to predict, evaluate and assess the aspects and impacts of floating PVs. To test and validate the framework, the results chapter is used to evaluate the sustainability of a fictional energy project where a floating PV system is planned to be installed in an urban area. Therefore, technical, economic, environmental, and social aspects and impacts of such a PV technology are identified, evaluated, and assessed. The results of the evaluation are analysed to understand whether a floating PV system can be implemented in an urban area sustainably. In the case the assessment allows to generate valuable conclusions that positively describe the sustainability of the system considered, it would be reasonable to propose floating PV systems as a possible socio-technical solution to make neighbourhoods more sustainable and to reduce the CO_2 emissions of cities. Finally, it is discussed whether the framework developed can be recommended as the first universal procedure to carry out the sustainability evaluation of future floating PV solar energy systems in cities.

1.5 RESEARCH QUESTION

From the problem statement and the description of the research objective, it is possible to develop the research question and sub-questions to be answered in this project. The research question is:

How can the sustainability of a floating PV system in an urban neighbourhood be assessed using a decision-support framework and specific methodologies?

To answer this research question, four sub-questions are proposed:

1. *How is a decision-support framework implemented in an energy project to carry out a sustainability assessment of a power plant prior to installation?*
2. *What methodologies must be used to select a suitable location and the system's components, and identify, evaluate and assess the aspects and impacts of a floating PV system?*
3. *Can a decision-support framework assess with specific methodologies the sustainability of a floating PV system in an urban neighbourhood?*
4. *Can a floating PV system be sustainable in the urban neighbourhood selected?*

The first sub-question is answered by developing a state-of-the-art decision-support framework that describes how such a tool should be implemented in an energy project to carry out the sustainability assessment of a floating PV system. Such a description is focused on specifying the structure of the framework, the steps needed to carry it out, and the elements that allow its application in a real-life project, i.e., the use of sustainability indicators. To do it, a synthesized decision-support tool is developed as a conceptual model by combining the content of journal papers and company reports. The limitations of such a tool are identified to develop a state-of-the-art decision-support framework. This latter is thus illustrated so that engineers can use it to predict the aspects and impacts of the development stages of an energy project. The first sub-question is thus answered in the last section of the theoretical framework. The second sub-question is answered by describing the specific methodologies that allow engineers to carry out the sustainability assessment of floating PV systems in an urban area. Therefore, the processes that enable the selection of a suitable location and the system's components, identify indicators, evaluate them, and generate data and information to assess them are thoroughly described in the methodology chapter. The third sub-question is practically answered by testing the state-of-the-art framework and methodologies proposed in a fictional energy project where a floating PV system is implemented in a district of a city. The third and fourth sub-questions are thus elaborated in the analysis of the results. By solving these four sub-questions the main research question can be answered in the conclusion of the paper to clarify how the sustainability of a floating PV system can be assessed using the proposed framework and methodologies.

2. THEORETICAL FRAMEWORK

To develop a state-of-the-art decision-support framework for the evaluation of floating PV projects in an urban neighbourhood, it is important to comprehend what sustainable energy development in cities means, what floating PVs are and how a decision-support framework is implemented in an energy project to perform a sustainability assessment before installation. In this chapter of the paper, a literature review is done to define sustainable development and contextualize it in the urban energy sector by describing the related United Nations Sustainability Development Goals (SDGs). Also, an overview of floating solar systems is reported to provide a theoretical background of the technology and link it with the concepts of sustainable energy development and sustainability assessment. Subsequently, the content of five studies is synthesized to define how a sustainability assessment for an energy system is currently carried out. Therefore, a synthesis of their content is illustrated as a step-by-step conceptual model that shows a preliminary decision-support framework. The limitations of such a conceptual model are then identified, and a state-of-the-art decision-support framework is developed. The implementation of such a framework in an energy project is thus illustrated. This final product will be the backbone to assess the sustainability of a floating solar system in the built environment.

2.1 SUSTAINABLE ENERGY DEVELOPMENT IN CITIES

With the publication of "Our Common Future" in 1987, the World Commission of Environment and Development defined sustainable development as meeting the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). In the report, the role of energy in achieving sustainable development was officially recognized as increasing energy efficiency, reliability and reducing the environmental impact of power generation (Steg, Werff, & Perlaviciute, 2015). This recognition put energy generation in a central position to achieve sustainable development but failed to provide precise dimensions to focus on and objectives to be achieved. Besides, the role of cities to attain this common issue was not specified in "Our Common Future". It was not until the release of the United Nation's SDGs in 2015 that clear dimensions and targets for sustainable energy development in cities were established (Gunnarsdottir, Davidsdottir, Worrell, & Sigurgeirsdottir, 2021). As a matter of fact, the SDGs determined three dimensions to focus on in order to achieve sustainable development, namely the environment, the economy, and the society. By focusing on these three dimensions, the United Nations SDGs translated the concept of sustainable energy development into actions using decision-support tools that enable to carry out a sustainability assessment of socio-technical systems and processes (Evans, Strezov, & Evans, 2009). As a result, to be sustainable, an energy system must bring environmental, economic, and social advantages throughout its lifetime. This means that it must not negatively affect the surrounding ecosystem and socio-economic assets of an urban area during the planning, construction, and operation & decommission stages. Such a principle is translated into the SDGs objectives. Among the 17 SDGs released by the United Nations, there are three goals directly connected to promoting sustainable development while achieving an urban energy transition. These are SDG 7, SDG 11, and SDG 13 (Figure 2) (Nations, 2015).

Figure 2: The Sustainable Development Goals connected to this research project (Nations, 2015).

SDG 7, affordable and clean energy, refers to ensuring universal access to cheap electricity by investing in clean energy technologies, such as solar PVs. The main objective is to meet the growing energy demand of cities by providing green and economical electricity and minimizing pollution to improve the livelihood of people. To achieve this goal the technical and economic dimensions of a SET must be assessed. Also, the energy and economic performance of the energy system must be optimized to achieve this goal.

SDG 11, sustainable cities and communities, focuses on sustainably implementing SETs so that current and future generations can benefit from them. This means improving the safety and livelihood of urban areas by creating green districts and developing urban planning and management in a way that is participatory and inclusive. Achieving this goal requires social inclusion and participation in the political agenda to enable collective decisions to be taken. Besides, local investments of public and private institutions in SETs are important to enable an energy system to economically benefit residents and promote the sustainable development of cities and communities. In this regard, it is also important to make sure that the implementation of SETs boosts the local economy by creating jobs. In this case, the attention lies in the social, economic, and environmental aspects and impacts related to the implementation of a socio-technical system in a city and a community.

Finally, SDG 13, climate action, aims to mitigate climate change by implementing renewable energy systems in society to produce green energy and reduce CO_2 emissions. To achieve this goal, technical and environmental dimensions must be considered.

These SDGs highlight that the concept of urban sustainable energy development must be applied in terms of the technical features of an energy system and its three pillars embracing economic growth, social equity, and inclusion, and environmental protection and enhancement (Nations, 2015). As a result, a solar installation must promote these principles to make sure that its implementation is sustainable, meaning that when assessing the sustainability of a floating PV system it is essential to focus on the technical, economic, environmental, and social aspects and impacts of the technology. These are related to the planning activities, namely selecting a suitable location for the floating PV power plant so that its energy and economic performance can be optimized, and its environmental and social impact minimized. Similarly, the choice of the system's components determines its effects on the surrounding ecosystem and society. Finally, the construction and operation & decommission activities must be identified and assessed to understand their potential impact on the location.

2.2 FLOATING PV SYSTEMS

Now, the most common technical, environmental, social, and economic aspects of floating PV systems are illustrated. This overview helps to create a link between the solar power plant and the concept of sustainable energy development and sustainability assessment. In fact, it clarifies why selecting the right components and a suitable location are essential considerations when it comes to evaluating the sustainability of a floating PV power plant in the early development stages of the project.

A floating PV plant results from the combination of PV panels and floating technology (Figure 3).

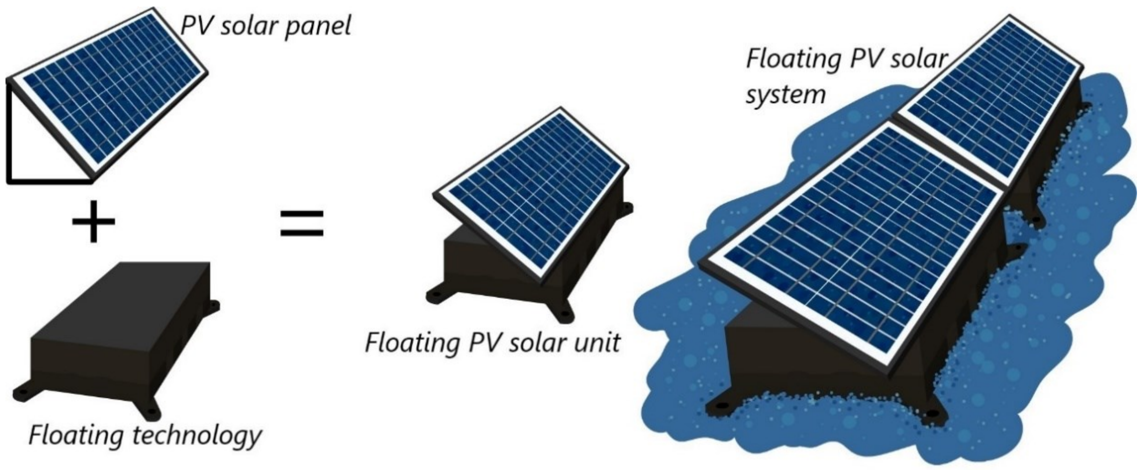

Figure 3: The composition of a floating PV unit and system (Ziar, et al., 2020).

A PV solar panel is combined with a polyethylene floating device (also known as pontoon) with buoyancy enough to float by itself as well as with a heavy load. The PV module is supported by an aluminum frame that is mounted on the pontoon. The result is a floating PV solar unit. Depending on the buoyancy of the pontoon, a floating PV unit can consist of more than one PV panel or even several arrays. By connecting two or more PV units a floating PV solar system is created. Beside the PV modules and the pontoon structure, a floating PV system is composed of several underwater elements (Figure 4). The most relevant components are the mooring line, the anchoring system, and the underwater power cables. The mooring and anchoring systems keep the panels in the same position and prevent them from turning or floating away. The installation of these systems can be a challenge and expensive in deep water. Mooring systems can be done with metal or nylon wire ropes. The anchoring device can be heavy concrete or metal weights that lie at the bottom of the water body. However, using large blocks may affect the ecosystem. Therefore, the anchoring system can also be created by planting small devices under the seabed. The underwater power cables draw electricity from the floating PV array and transport it to the land, where it is converted from Direct Current (DC) into a utility frequency Alternating Current (AC) by a solar inverter or power conditioning system. At this point, electricity can be fed to the grid or stored in batteries. The choice of these components determines the stability and size of the floating PV system and are thus essential considerations to be made to start the planning stage of an energy project (Hernandez, Hoffacker, Murphy-Mariscal, & Wu, 2015).

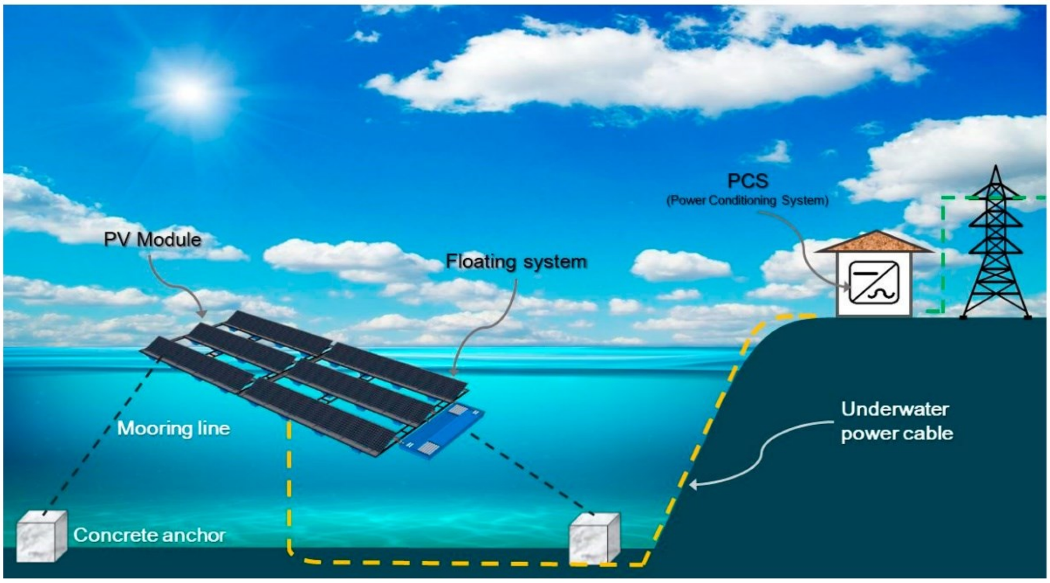

Figure 4: The components of a floating PV energy system (Extebarria, 2018).

Floating solar installations have major advantages over more traditional PVs like rooftop and ground-mounted panels. As a matter of fact, floating systems are an innovative solution to boost the efficiency of solar installations while gaining economic and environmental advantages and saving land (Shau, Yadav, & Sudhakar, 2016). The efficiency of solar panels decreases as the internal temperature of a cell increases (B.Parida, S.Iniyan, & R.Goic, 2011). Therefore, installing PV systems on water bodies exploits low ambient temperatures to prevent excessive heating of the modules in virtue of the cooling effect of water. This helps the solar modules to perform at high efficiency for longer periods than land PV panels. On average, the efficiency of floating solar panels is 15% higher compared to ground-mounted and rooftop installations (Shau, Yadav, & Sudhakar, 2016). To ensure that this advantage is exploited during the lifetime of the power plant, it is essential to select a water body whose water level remains constant throughout the year. Therefore, the selection of the location is strictly related to the conditions of the water body considered during different seasons. Besides, the efficiency of PV panels depends on the amount of sunlight a location receives. It is thus important to make sure that the water body selected is not substantially covered by shading from the surrounding elements throughout the day so that the panels can receive as much sunlight as possible.

The efficiency of floating PVs can be further increased by enabling the panel to absorb the albedo, namely the sunlight that is reflected by the water surface (Figure 5).

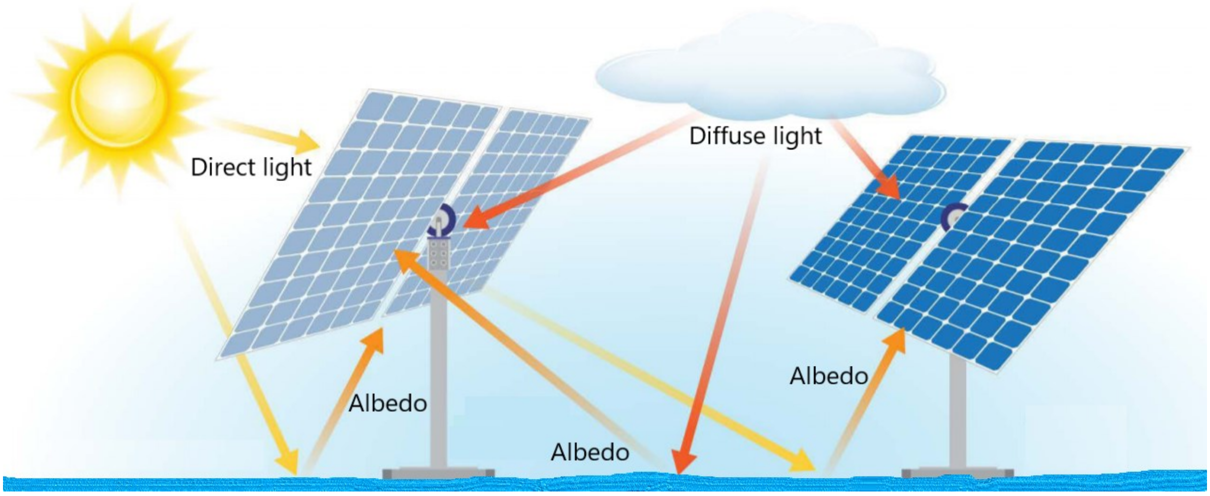

Figure 5: Composition of sunlight in the atmosphere. Direct light is the un-scattered light that hits the surface of a PV cell and changes the angle of incidence depending on the time of the day and year. The diffuse irradiance is the light scattered due to the atmosphere, the clouds, and the surroundings. This diffuse irradiance enters a solar cell from various angles of the panel. The other interesting aspect of the incoming irradiance is the albedo, i.e., ground reflected light. Albedo is thus the ground-reflected direct and diffuse light (W.H.Li & D.S.Lou, 2018).

The intensity of the albedo is strictly related to the type of material it is reflected on. Light coloured materials are good reflectors, i.e., snow, water, while dark ones, i.e., asphalt, absorb most of the light and thus do not reflect much irradiance (W.H.Li & D.S.Lou, 2018). This is of particular interest to bifacial solar cells, as they absorb light from the front and the rear face. This feature enables floating PVs to convert electricity from the water-reflected light as well as from the direct and diffuse irradiance, thus, enabling a power conversion efficiency of over 35% (W.H.Li & D.S.Lou, 2018). In this regard, given that the higher the efficiency the more affordable an energy system, floating PVs are expected to become the cheapest solar application in the market in terms of cost of electricity and payback time (B.Parida, S.Iniyan, & R.Goic, 2011). Therefore, the choice of PV technology is also an essential consideration to be made to ensure high levels of efficiency and low costs.

Floating PV installations also have the benefit of not requiring land. On average, to produce 1 MW of solar energy, approximately 16000 m2 are required. As a result, PV systems need significantly larger land areas compared to conventional power plants. For instance, a 100 MW thermal power plant would require less than 10% of the total area that a 100 MW solar PV power plant would need (Byrne, Taminiau, Seo, Lee, & Shin, 2017). The land occupied by solar farms could be used in other ways that are valuable for the built environment, especially in cities with high population density and limited usable land (Aman, et al., 2015). Consequently, floating PVs have another economic advantage because the costs of ground allocation can be minimized along with problems related to land availability

(Acharya & Devraj, 2019). This is an important matter to consider when selecting the location for the installation and predicting and assessing the economic aspects and impacts of floating panels.

Furthermore, floating PV plants have advantages from an environmental perspective. They can reduce water loss due to evaporation by up to 33% on natural lakes and ponds, and by about 50% on reservoirs and canals by providing shading. Besides, shading can improve water quality by preventing an excessive amount of oxygen from accumulating below the surface, keeping algae to grow uncontrollably. Nevertheless, this feature can also lead to oxygen deprivation in the aquatic ecosystem, which in turn can threaten the flora and fauna of a lake or a canal (Shau, Yadav, & Sudhakar, 2016). It is thus important to evaluate the biochemical characteristics of the water body selected in order to understand the possible environmental impacts of the floating power plant on the aquatic ecosystem. Again, the selection and evaluation of the location is a central issue to consider.

However, floating PVs also have several technical, environmental, and social issues. As a matter of fact, solar modules, and the components of the floating system, particularly the elements that are underwater, are constantly exposed to a wet and dynamic habitat. These conditions represent major technical and environmental challenges, like structural failures due to corrosion can occur over time, and moisture can penetrate the modules causing loss of efficiency (Ziar, et al., 2020). Corrosion of metals and damages to PV panels can release toxic substances in the water, disrupting the ecosystem and threatening the well-being of the aquatic flora and fauna. Similarly, adverse weather conditions, like waves and strong winds, can decrease the performance of the system by damaging the floating structure or the panels, which in turn can cause unwanted matter to be released into the water. Consequently, high-quality water-resistant materials must be used to encapsulate the components of a floating PV system and keep them from being in direct contact with water (Ziar, et al., 2020). Another technical and environmental issue is transporting the electricity generated from the water to the land safely and reliably. To do it, underwater cables must connect the floating PV plant with the power converter station on land. Therefore, regardless of the quality of the connection, the possibility of electrical accidents that endanger the biodiversity of the aquatic ecosystem persists throughout the lifetime of the power plant (Acharya & Devraj, 2019). Choosing high-quality components, a water body with small dynamicity, and monitoring and maintaining the whole system is thus essential to ensure safety to society and the environment. In addition, floating solar systems may affect socio-economic activities that are carried out on a water body, like fishing and transport. Also, these installations have the burden of changing the appearance of the landscape in which they are installed, meaning that they are often coupled with low social acceptance (Isabella & Ziar, 2018). Therefore, a suitable location is where socio-economic activities that depend on the availability of the water body are not hindered. Finally, floating PV systems are characterized by high installation costs, which are mainly due to the floating devices and the underwater components. In fact, these elements comprise 10-25% of the total cost of such PV power plants. Again, this issue highlights the importance of choosing economic but high-quality materials and components for the floating system.

2.3 SYNTHESIZED DECISION-SUPPORT FRAMEWORK TO ASSESS THE SUSTAINABILITY OF ENERGY SYSTEMS

To apply a sustainability assessment in a real-life energy project it is essential to understand how it can be implemented using a decision-support framework. A framework is necessary to guide engineers in a step-by-step process where specific elements related to the selection of the location and the components and the technical, economic, environmental, and social aspects and impacts of an energy system are identified and assessed. In this section, the first sub-question is answered by reporting a synthesized decision-support framework from existing papers and reports, identifying its limitations, and developing a state-of-the-art tool to carry out the sustainability assessment of an energy system. To do it, the content of five studies is synthesized in a step-by-step conceptual model. The papers are selected by carrying out a literature review, which starts by researching in academic search engines, i.e., Google Scholar and Scopus, the existing procedures used to assess the sustainability of energy systems. Therefore, several studies are read to select only those that propose a decision-support framework for assessing at least one of the sustainability dimensions. The result of this literature review is the selection of the five studies illustrated below.

- "Sustainability assessment of energy systems: integrating environmental, economic, and social aspects". This journal paper presents a conceptual model of a decision-support framework that facilitates the consideration of the environmental, economic, and social dimensions during the sustainability assessment of an energy system. The idea of developing a decision-support framework as a step-by-step conceptual model is proposed in this research paper (Santoyo-Castelazo & Azapagic, 2014).
- "A Framework for Sustainability Indicators at EPA". This is a report developed by the Environmental Protection Agency. It is focused on providing the methods and guidance to support the application of sustainability assessment of energy systems. Some of the methodologies proposed by the authors to evaluate the aspects and impacts of power plants are proposed in this paper. In particular, the definition of goals that are related to SDGs objectives and the assessment method, which uses such goals to evaluate the level of sustainability of the system under investigation (Fiksel, Eason, & Frederickson, 2012).
- "Sustainability assessment: the state of the art". This is a journal paper that focuses on developing a state-of-the-art sustainability assessment. The authors use the literature available at the time to propose five steps to evaluate socio-technical systems and processes. The procedures proposed are integrated to develop an updated state-of-the-art decision support framework (Bond, Morrison-Saunders, & Pope, 2012).
- "Assessment of sustainability indicators for renewable energy technologies". This journal article illustrates how environmental, economic, and social aspects and impacts are identified and analysed in a sustainability assessment using indicators. Therefore, some of the indicators

and methodologies used by the authors are proposed in this research project (Evans, Strezov, & Evans, 2009).

- "Is floating photovoltaic better than conventional photovoltaic? Assessing environmental impacts". This journal article aims to develop a procedure to evaluate the environmental impacts of floating PV systems during the development stages of the project. The concept of implementing the environmental assessment of a power plant during the different stages of a PV energy project is used to develop the final state-of-the-art decision-support framework (Silva & Branco, 2018).

By merging the content of these papers, it is proposed a preliminary and synthesized decision-support framework consisting of selecting an energy system and a location, defining the related sustainability goals, and identifying, analysing, and evaluating indicators to carry out the assessment (Figure 6). Each step of the conceptual model is illustrated below.

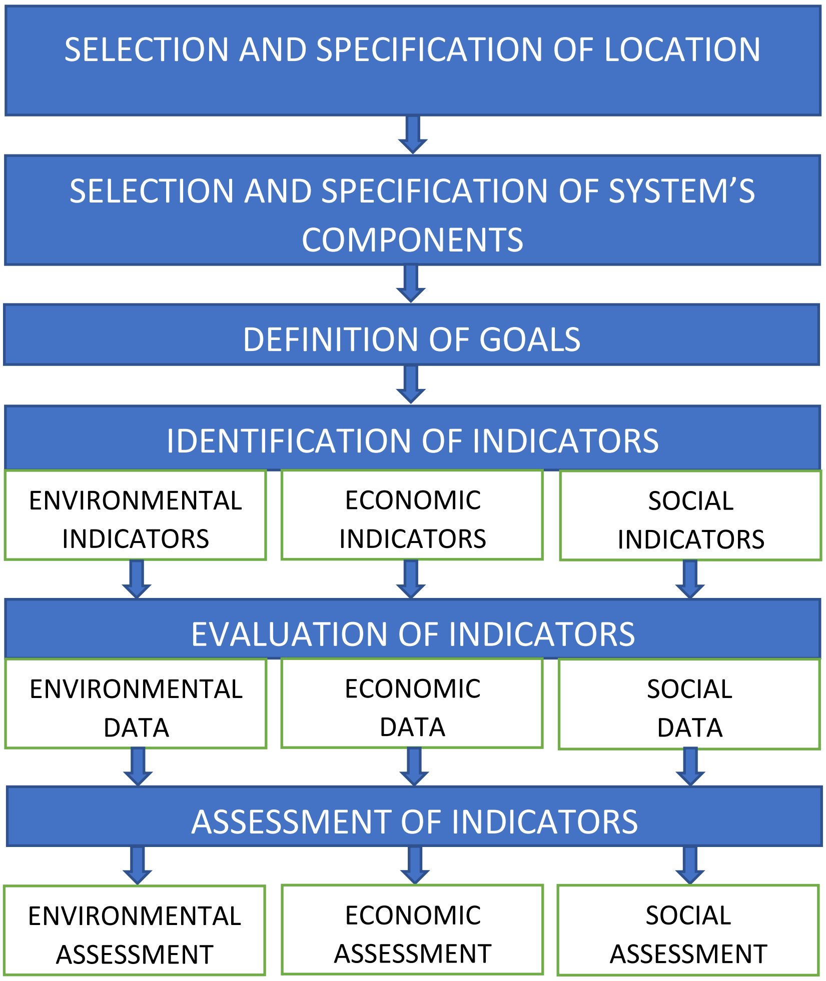

Figure 6: Conceptual model of the preliminary decision-support framework that synthesizes the content of the five papers selected to carry out a sustainability assessment of an energy system.

The first step refers to selecting and specifying the characteristics of the location in order to evaluate whether it is suitable or not for the installation of an energy system. It is thus important to report elements like the available area for the installation, the socio-economic and political features of the location, and the physical elements of the surroundings (Devuyst, Hens, & Lannoy, 2001). In the second step, the components of the installation must be selected and specified. Subsequently, the goals must be set to define what is sought to be achieved throughout the lifetime of the power plant considered. They are based on the SDGs' objectives and specific characteristics of the energy system and the area selected (Fiksel, Eason, & Frederickson, 2012). The possibility of achieving these goals is evaluated using indicators. Sustainability indicators are valuable tools for purposes of problem analysis, reporting of progress, evaluation of outcomes, and assessment of performance. They can be used to produce, evaluate and assess the environmental, economic, and social aspects and impacts of an energy system prior to installation (Fiksel, Eason, & Frederickson, 2012). Indicators can be both qualitative and quantitative and they must be categorized in one of the three sustainability pillars. The number of indicators considered in current literature varies from four (4) to seventy-five (75), depending on the type of system and location considered (Santoyo-Castelazo & Azapagic, 2014). Examples of indicators can be seen in Figure 7.

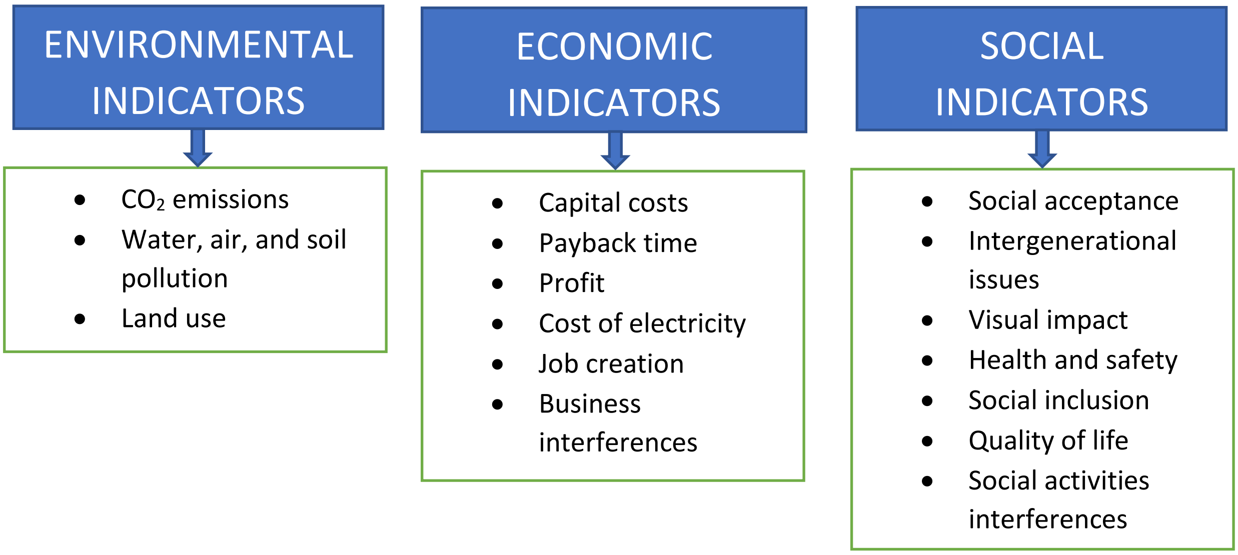

Figure 7: Some of the sustainability indicators related to the assessment of energy systems. This information was collected from the five papers and reports.

The identification, evaluation, and assessment of indicators require the collection of data and the use of different evaluation methods that are specific to the installation and location selected. During the analysis of indicators qualitative and quantitative results are generated. These illustrate the aspects and impacts of the energy system and the location specified. Finally, the results of the indicator analysis are assessed by comparing them with the goals sought to be achieved, so that conclusions that describe the sustainability of an energy system in a geographical area can be drawn (Fiksel, Eason, & Frederickson, 2012). This procedure provides a summarized explanation of how engineers can carry out the sustainability assessment of energy systems according to the five journal papers and reports reviewed.

2.4 LIMITATIONS OF THE SYNTHESIZED DECISION-SUPPORT FRAMEWORK

However, the synthesized decision-support framework in Figure 5 has three major limitations. One is related to the lack of technical indicators focused on the energy-related issues and management of the system. These are essential to generate specific quantitative data and qualitative information to evaluate the energy performance and contribution of the power plant. Therefore, technical indicators must be included as an additional sustainability pillar in the decision-support framework. Examples of technical indicators can be seen in Figure 8 (Afgan, Carvalho, & Hovanov, 2000).

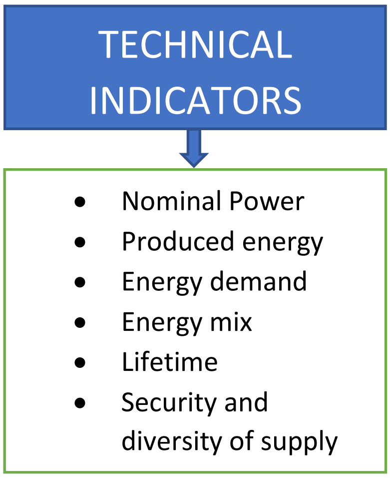

Figure 8: Some of the technical indicators relevant to the sustainability assessment of an energy system.

The second limitation is that the synthesized decision-support framework needs specific data collection and analysis methodologies to be implemented for the sustainability assessment of an energy system. Nevertheless, journal papers and reports rarely describe them in an integrated and applicable manner for a specific power plant and its location (Evans, Strezov, & Evans, 2009). Therefore, the methodologies necessary to identify and analyse indicators for the sustainability assessment of a specific energy system, like a floating PV system, are often unknown or very difficult to find and evaluate. As a result, it is necessary to develop a framework that includes specific methodologies for each type of energy system. Besides, it is not clear what criteria must be considered when selecting a suitable location and the right technologies for the energy system.

The last limitation is that there is no relation between the decision-support framework and its real-life implementation in a project (Afgan, Carvalho, & Hovanov, 2000). In fact, it is not clear how this framework should be implemented in the development stages of an energy system prior to installation. Consequently, engineers have been struggling to use such a tool to evaluate the specific activities related to each stage of a project. The development of energy systems consists of three stages: planning, construction, operation & decommission (Figure 9).

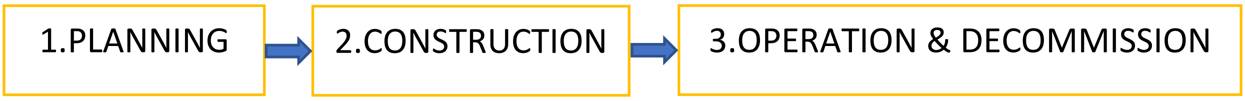

Figure 9: The three development stages of an energy system project.

Planning includes evaluating the suitability of a location by reporting the area's spatial characteristics and the features of the energy technologies involved to define precise goals. The construction stage requires the management of the installation work in a way that the system will operate at optimal performance. The construction of a PV plant is considered the most impactful stage of the project, as its activities affect the environment, the economics, and the community. Finally, the operation & decommission stage consists of monitoring and maintaining the high performance of the energy system throughout its lifetime. Maintenance is an essential activity at this stage. In addition, during this stage, the energy system is dismantled at the end of its lifetime. These activities also have an impact on the ecosystem, economics, and society. As a result, the construction and operation & decommission stages also require sustainable management of their activities to ensure minimal negative effects on the geographical area and optimal performance of the system (Afgan, Carvalho, & Hovanov, 2000).

2.5 STATE-OF-THE-ART DECISION-SUPPORT FRAMEWORK TO ASSESS THE SUSTAINABILITY OF ENERGY SYSTEMS

Now that the limitations of the synthesized framework are known, it is possible to propose a state-of-the-art decision-support tool to facilitate its implementation in a real-life energy project. By adding the technical indicators as an essential sustainability dimension to be assessed and juxtaposed with the goals, a complete and integrated framework can be proposed. In addition, by relating each development stage to the corresponding step of the framework, it will be easier for engineers to implement the conceptual model in real life (Silva & Branco, 2018). The state-of-the-art decision-support framework is illustrated in Figure 10.

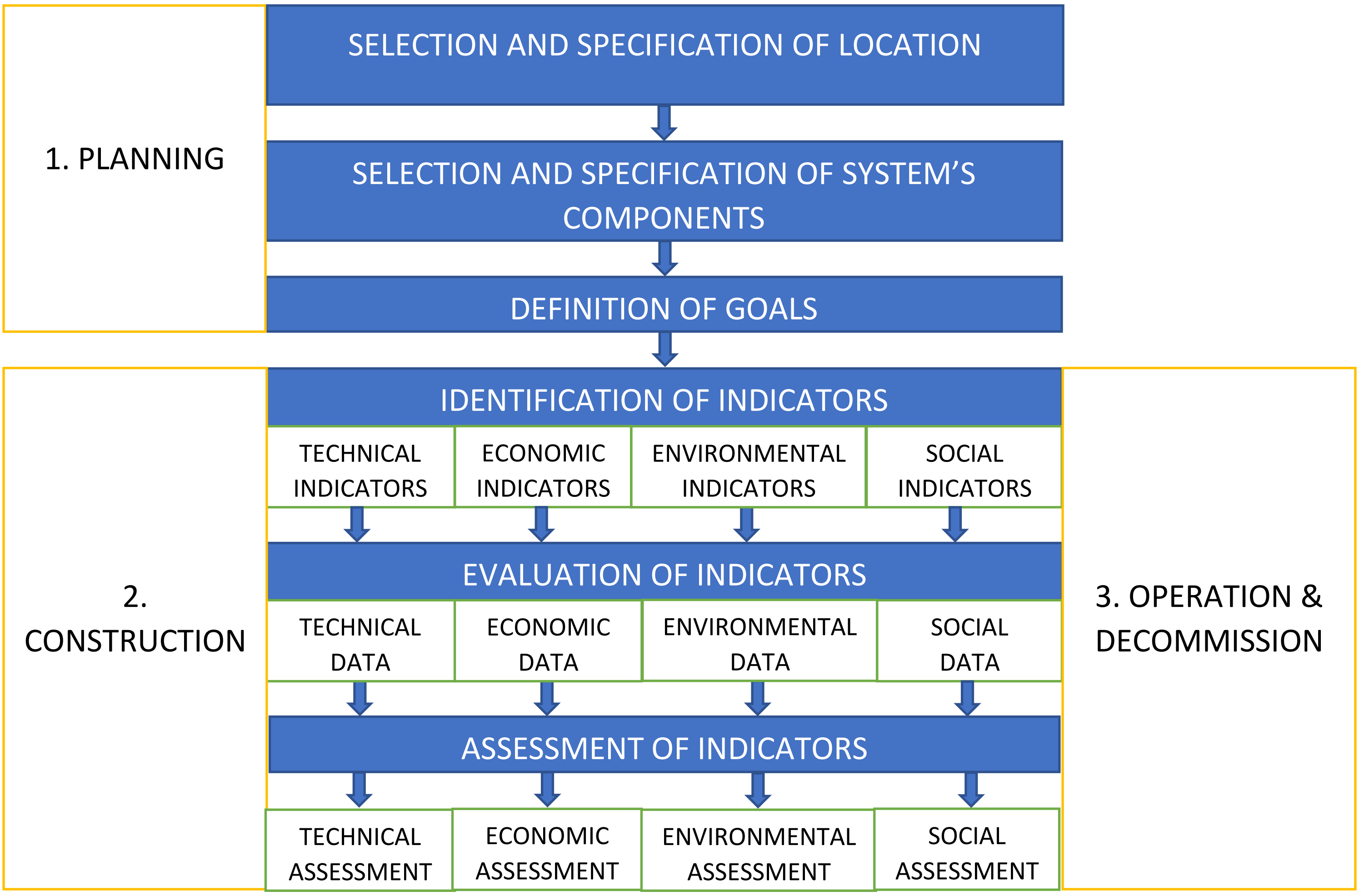

Figure 10: Conceptual model of the state-of-the-art decision-support framework for the sustainability assessment of an energy system.

As mentioned, an energy project begins with the planning stage, where the geographical area and technologies considered are analysed and goals are defined. The corresponding steps of the framework are selecting and specifying a suitable location and energy technology and defining the goals sought to be achieved. Therefore, the first three steps of the framework must be carried out during the planning stage. This will enable engineers to have a clear overview of the physical, social, economic, and political characteristics of the area to evaluate its suitability. Similarly, the technical aspects of the energy technology are considered so that the right components can be specified. By keeping these aspects in mind and combining them with the objectives of the SDGs related to urban sustainable energy development, specific goals can be defined. Subsequently, the second stage, namely the construction of the energy system, starts. The corresponding steps of the framework are the identification of sustainability indicators, their evaluation, and, finally, their assessment. These are related because construction works inevitably affect the surrounding ecosystem and community, meaning that the technical, environmental, social, and economic dimensions are involved. To evaluate the aspects and impacts of the installation activities, the related sustainability indicators must be identified and examined using specific data collection and analysis methods that depend on the energy system and area considered. In addition, to evaluate the construction stage, it is important to consider the impacts of the manufacturing processes of the components. The last development stage, operation & decommission, requires the same procedure. In fact, also the activities related to the operation and maintenance of the system affect the environment, economics, and society. Similarly, the decommissioning of the power plant influences a community and its ecosystem, meaning that indicators must be identified and assessed to evaluate the aspects and impacts at this stage of the project. As a result, during the construction and the operation & decommission stages, technical, environmental, economic, and social indicators must be identified, analysed, and assessed. Therefore, the fourth, fifth, and sixth steps of the framework must be carried out during the second and third development stages of an energy project. Finally, the results of the assessment are juxtaposed with the goals to understand the possibility of their achievement and draw valuable recommendations and conclusions related to the sustainability of the energy system considered. The description of this step-by-step conceptual model explains how a state-of-the-art decision-support framework can be implemented in an energy project to carry out the sustainability assessment of a power plant prior to installation so that aspects and impacts, are identified, evaluated, and assessed. The first sub-question is thus answered.

However, when applying this decision-support framework to assess the sustainability of a specific energy system, selection of the location and the system's components, the definition of goals, the identification of indicators, and evaluation methods depend on the type of power plant and the location considered. For instance, assessing a ground-mounted solar PV system in a neighbourhood requires different criteria to select a location and the technologies, goals, indicators, evaluation methods, and data than the assessment of a wind turbine in the countryside. Consequently, to develop a specific decision-support framework for assessing floating PV systems, it is important to use specific evaluation methods for data generation and analysis. In this way, a suitable location can be selected, the right components chosen, and the appropriate indicators identified, evaluated, and assessed. The rest of the paper is dedicated to specifying and applying the specific methods that are used to carry out the sustainability assessment of a floating PV plant in an urban district. The second sub-question is thus answered in the next chapter. Finally, the results are discussed, and conclusions are drawn to provide an ultimate answer to the research question and finalize the conceptual model of the framework designed by including the specific methodologies necessary for the sustainability assessment of a floating PV system in an urban area.

3. METHODOLOGY

An empirical and holistic approach is used to carry out a case-study research that focuses on selecting a suitable location and the right components, and identifying, evaluating, and assessing the economic, environmental, technical, and social aspects and impacts of a floating PV system in a neighbourhood of a city. To do it, different methods and evaluation techniques are carried out for each step of the framework. A location and the system's components are suitable only if precise criteria are met. As a case-study, a water body in Leeuwarden, the Netherlands, is selected, and its characteristics are specified to evaluate its suitability for the implementation of a floating PV system. Similarly, the selection of the system's components is done in accordance with specific criteria. Goals are then defined in accordance with the three SDGs previously considered. Subsequently, indicators that are specific to floating PVs are identified. Next, the evaluation of indicators begins using different tools and techniques so that qualitative information and quantitative data are generated. Finally, the results of the evaluation are assessed by comparing them with the goals sought to be achieved. Each of these steps is described within the corresponding development stage of the energy project.

3.1 CASE-STUDY SELECTION METHODS

The methodologies proposed to carry out the first two steps of the framework are now described as case-study selection methods. The selection and specification of the case-study, namely the location for the installation of the floating PV system and its components, is carried out based on several criteria. The methods used to evaluate whether the water body is suitable consist of using Google Earth, on-site observations, a 3-D modelling software, and literature, reports, and media review. These methods must be applied during the first step of the framework. On the other hand, literature and company reports, and 3-D modelling software are used as methods to choose the right components of the system. These methods must be applied during the second step of the framework.

3.1.1 SELECTION AND SPECIFICATION OF LOCATION

The selection and specification of the location are based on evaluating the suitability of an urban area for the installation of a floating PV system in accordance with political, socio-economic, and physical criteria. This means that a location can be considered suitable only when there are the right social, political, economic, and physical conditions to support the implementation of a floating PV system. It is important to start this phase by choosing a nation or a region and reporting its demographic features and political ambitions to develop the renewable energy sector. Subsequently, a municipality must be selected, and its political conditions related to SETs implementation must be briefly described. Such information can be retrieved by doing a literature review and researching on the web for reports related to national/regional/municipal energy plans. This is done to provide an overview of the national and local needs and commitments related to the implementation of sustainable energy development. Therefore, these data are useful to understand whether the political conditions for the implementation of SETs exist in the location considered. This is the first important criterion to be met to select a suitable location.

Next, a neighbourhood of the city must be chosen, and its political and socio-economic characteristics must be specified. The economic characteristics are analysed by reviewing official websites and reports of the region, municipality, or, even better, of the neighbourhood. In addition, aspects like the prices of the local housing market and the average income of a resident can be used to understand the wealthiness of the district. By comparing these data with the national averages, it is possible to have an overview of the wealthiness of the district selected. The wealthier the area, the more likely the financial support from the residents. Besides, it is important to understand how the neighbourhood is managed and whether social inclusion in the decision-making processes is a central issue. Therefore, the good socio-economic situation of the area is also an important criterion to be met to select a suitable location. In the case this information is not available online or does not exist, interaction with the municipality and/or neighbourhood representative is suggested.

Only when the political and socio-economic characteristics of the city are known, a specific area for the installation is selected by following precise physical criteria, so that its technical suitability can be examined. The presence of water inland bodies in the area is an essential criterion to be respected. Besides, it must be large enough for the installation of a floating PV system and its water level must not change substantially throughout the year. In addition, the water body, which can be a lake, a reservoir, or a canal, should receive a substantial amount of solar electromagnetic radiation throughout the day. Consequently, the waterway must not be surrounded by particularly tall buildings or trees. To meet these criteria, qualitative and quantitative data are collected via spatial analysis using Google Earth. The 3-D and measurement features of the cloud-based geospatial platform are applied to collect information on the surrounding elements and the space available in m^2, respectively. Once a specific location is identified, the most reliable approach to further evaluate its potential is to do on-site observations. Consequently, the location must be visited to understand whether the Google Earth spatial analysis was accurate or not. To do it, the on-site examination is done while interacting with the Google Earth application opened on a device. In the case it is noted that there are substantial differences from such an analysis, a new location should be considered. To further investigate the technical suitability, it is important to keep in mind that, in the northern hemisphere, the general rule for solar panel placement is that they should face true south (and in the southern, true north). Therefore, on-site empirical analysis is important to observe whether the shading of the elements south or north (depending on which hemisphere the place is located) the installation area cover the water surface. This is done to generate hourly data of the shading patterns during morning and evening and empirically decide whether the water body selected is suitable for the energy project. Next, data are further generated by developing a faithful digital 3-D model of the area. The software used to make the model is SketchUp Pro 2021. However, any other 3-D modelling software that can import a 3-D geographical area from Google Earth and enable shading analysis can be utilized. Such a model is used to generate visual data concerning the shading patterns of the surrounding elements throughout the day and the year. This is done to make sure that the water surface receives enough sunlight for a floating PV system. These procedures enable engineers to collect data and information that help them to select the area that is technically suitable for the installation of a floating PV system. To sum up, the criteria to be met in order to select a suitable location are reported in Table 1.

Political	National and local legal commitment towards the implementation of sustainable energy development and SETs.		
Socio-economic	Wealthy urban area.	Social inclusion in the decision-making processes.	
Physical	The presence of a water body is large enough for the installation of floating PVs.	The level of water must not change substantially throughout the year.	The water body must receive a substantial amount of sunlight throughout the day.

Table 1: Political, socio-economic, and physical criteria to be met to select a suitable location for the installation of a floating PV system in a city.

3.1.2 SELECTION AND SPECIFICATION OF SYSTEM'S COMPONENTS

Besides the location, the energy system and its components are also selected and specified using literature, reports, and 3-D modelling software. The main objective of this phase is to collect real-life data of the components to design the energy system. A floating PV power plant consists of a combination of two systems: the floating technologies and the PV modules. Therefore, two groups of data are collected, respectively. These are both qualitative and quantitative information retrieved from online literature and reports. To design the floating system, several components are researched, but only the most economic and efficient ones are selected. In fact, when researching and selecting components, it is important maintaining low costs (the components should not exceed 25% of the total installation costs) while ensuring safety and the correct operation of the system throughout time. It is thus essential to specify the floating system selected by describing the characteristics of the pontoon, the mooring device, and the anchors. In addition, given the moist and wet conditions that the system is exposed to, encapsulating materials should also be researched and specified through a literature review. Similarly, the selection of the PV system is based on data collected from studies and reports that analysed the technical aspects of PV panels installed above water. Again, when selecting the PV module, it is important maintaining low costs while optimizing the efficiency (at least 30% efficiency should be achieved) and safety of the panels. To design the energy system, information that illustrates the characteristics of the PV plant and its components is collected. As a result, it is important to describe features like the type of PV panel, its dimensions, the support frame, its efficiency and nominal power, the number of panels, their orientation, and tilt. In addition, these data are used to generate a realistic digital 3-D model of a floating PV solar unit using SketchUp Pro 2021. Therefore, the final product of this phase must be a realistic digital 3-D model of a floating PV unit. The economic and technical criteria to be met for the selection of the system's components are summed up in Table 2.

Economic	Maintaining low costs.	
Technical	Optimizing efficiency (30% efficiency should be achieved by the system).	Ensuring safety and operation of the floating PV system.

Table 2: Technical and economic criteria to be met for the selection of the floating PV system's components.

3.2 DEFINITION OF GOALS

The goals must be defined by keeping in mind the objectives of the SDGs 7, 11, and 13 so that they aim to promote urban sustainable energy development. In addition, the characteristics of the location and the energy system must be integrated with the SDGs objectives to define specific goals. To do it, the concept of urban sustainable development is related to floating PV systems and the socio-economic, political, and physical features of the area. Therefore, specific goals that concern topics like meeting the growing energy demand of a neighbourhood by providing green and economical electricity from a floating PV system are defined. With the definition of goals, the planning stage of the energy project ends to give space to the construction and operation & decommission activities.

3.3 IDENTIFICATION OF INDICATORS

To guide engineers in the implementation of the framework in a real-life energy project, indicators related to the construction activities must be selected before those belonging to the operation & decommission stage. The indicators that are identified for these stages are evaluated to generate data and information that are used to assess whether the activities related to the implementation of a floating PV system in a neighbourhood can be sustainable. They must be measurable or analytical aspects of the floating solar system that allow evaluating the possibility of achieving the goals previously defined. For one goal, one or more indicators can be identified. For instance, if the goal is reducing CO_2 emissions in a geographic area, the indicators can be the amount of CO_2 emitted and the amount of replaced CO_2 emissions during operation. Indicators for each pillar of the decision-support framework are identified. Technical indicators must be related to energy, construction, and operation & decommission issues; economic indicators must refer to the costs and profits of the energy system, its payment, its construction, and its operation & decommission; environmental indicators must concern the current and future conditions of the ecosystem, and pollution sources; finally, social indicators must represent the aspects linked with social acceptance of the power plant and social inclusion in the decision-making processes. Their identification is supported by literature and reports review. In fact, many studies have already recognized a vast number of indicators for solar energy systems. Academic search engines are thus used to research reports that have assessed at least one of the four sustainability dimensions of the framework. As a result, the data generated during this step correspond to the indicators that must be selected for the sustainability assessment of floating PV systems. Nevertheless, it is important to mention that only the indicators that can be assessed for this research project are identified. This is due to the fact that often indicators require specialized and expensive equipment to be analysed and that the resources available for this project do not enable the use of such devices. For instance, the levels of oxygen and rate of algae growth are essential indicators to analyse the actual effects of a floating PV system on the aquatic ecosystem. To measure these factors specialized equipment is necessary and speculation should be avoided. Therefore, for this research project, these types of indicators are not considered.

3.4 DATA GENERATION METHODS

The methods used to generate data consist of literature and reports review, SketchUp Pro 2021, PVsyst 7.2, i.e., a solar energy and economic simulation software, and a survey. These methods are described in accordance with the sustainability pillar that is being researched and measured. They must be applied during the fifth step of the framework. Therefore, they are used to evaluate the aspects and impacts and generate data through which sustainability indicators are finally assessed.

3.4.1 EVALUATION OF INDICATORS

The indicators must be analysed with different methods based on literature and reports review, SketchUp Pro 2021, and PVsyst 7.2 i.e., a solar energy and economic simulation software, and a survey. These methods are described in accordance with the sustainability dimension that is being analysed. In addition, the indicators related to the construction stage are analysed before those of the operation & decommission.

The first indicators to be analysed are the technical ones. To do it, SketchUp Pro 2021 is used and a 3-D model of the location and the floating PV system considered is developed. A digital model helps to visualize the area and establish the exact position and shading patterns of the system. Consequently, the analysis of technical indicators consists of evaluating whether the construction and the operation & decommission stages can be carried out by ensuring optimal performance and minimal negative effects. The space available (in m^2) for the installation is the main input to establish the size of the floating PV system. As a matter of fact, the area previously selected is imported into the software and floating PV arrays are positioned into it. Through SketchUp, a shading analysis of the model is performed to space the solar arrays in a way that their shading patterns do not cover each other. This is done to make sure that the system can achieve optimal energy performance and to create an accurate digital model that will help to manage the construction stage. The 3-D representation is developed by combining this model with the one previously made so that the solar installation is positioned in an area that is not covered by the shading of the surrounding elements. This is done to provide a faithful scenario of the installation, which can be used to manage the construction activities in a way that the PV panels are exposed to sunlight as much as possible. Similarly, such a scenario helps to define the accessibility of the power plant in order to enable its maintenance and decommission. The nominal power (Watt-peak) of the floating PV system can be calculated by multiplying the number of modules and the nominal power of one panel. To evaluate other technical indicators, namely the energy-related issues, of the floating PV system, the software PVsyst 7.2 is used. This software allows simulating the energy performance of a PV system using inputs like the meteorological data of a location (available online), the area available for the installation, and the nominal power of the power plant. Therefore, these data are automatically processed to measure technical aspects like the lifetime, energy produced per year, and energy losses. In addition, to evaluate indicators like the energy demand of a building, web search engines are used to find the average consumption of power per capita in that location.

The economic indicators of the floating solar system are also measured with PVsyst 7.2. As a matter of fact, by using the same inputs to measure the energy performance, this software allows simulating the economics of a PV system. Therefore, aspects like the Levelized Cost of Electricity (LCOE), return of investments, payback time, and financing are automatically processed. Besides, a survey is used to collect information related to the local willingness to pay for solar energy and a floating PV system. Such a survey consists of indicating the level of agreement with several statements. In addition, to evaluate indicators that the software cannot measure, i.e., job creation, literature and reports are reviewed.

Similarly, the environmental indicators are measured by collecting data from existing studies. Therefore, reports of companies and scientific studies that analysed the environmental impacts of solar energy and floating PVs are considered. Their findings are used to collect data and information that can predict the possible effects of the power plant on the ecosystem.

Finally, the social indicators are measured by doing a review of studies that analysed the local acceptance and effects on the neighbourhood of solar energy systems in urban areas. Furthermore, to investigate the residents' opinion on solar energy installation and specifically on the floating PV system designed, a survey is developed and sent to them. The survey is thus focused on understanding the social and economic acceptance of a floating PV system installed in an urban neighbourhood. To do it, this measurement method requires the generation of quantitative and qualitative data. To access relevant quantitative data, the survey includes some statements related to solar energy and floating PV system, and the respondents will have to express their level of agreement through a 5-points scale answers. In addition, the survey will include a section for suggestions, where informants can openly express their opinion on certain aspects and propose any idea related to the research project. This approach guarantees access to qualitative information. Through this primary data, specific social indicators can be further generated. Considering as many households of the neighbourhood as possible would enable the collection of relevant and realistic data. Besides literature and reports are reviewed to support the analysis of the indicators not covered by the survey.

These methods allow engineers to evaluate and eventually assess the technical, economic, environmental, and social indicators and are summarized in the figure below.

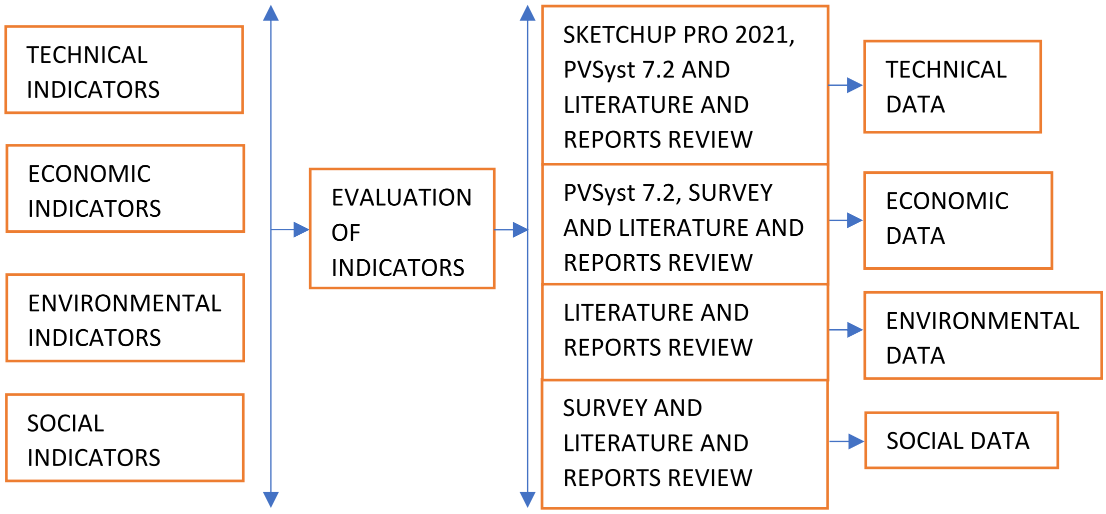

Figure 11: Conceptual model of the methodologies used to evaluate the indicators of the four dimensions of the decision-support framework and generate data and information needed for the assessment.

3.5 ASSESSMENT OF INDICATORS

The last step of the decision-support framework is the assessment of the results generated from the evaluation of each indicator. They are both quantitative data and qualitative information. The assessment of these data and information is carried out by juxtaposing them to the goals previously defined in order to understand to what extent they are achieved by the floating PV system. The assessment aims to understand whether the floating PV system can promote sustainable energy development in the neighbourhood considered and thus in an urban context.

In this chapter, the second sub-question is answered by describing the specific methodologies necessary to evaluate and assess the sustainability of a floating PV system in an urban neighbourhood during the development stages of the energy project. Therefore, the decision-support framework designed is tested and validated by applying it in a fictional energy project where an urban floating PV system is planned to be installed in a residential area.

4. RESULTS: APPLICATION OF THE DECISION-SUPPORT FRAMEWORK FOR THE SUSTAINABILITY ASSESSMENT OF AN URBAN FLOATING PV SYSTEM

To test and validate the decision-support framework, the methodologies proposed are applied in a fictional energy development project to predict the sustainability of a floating PV system installed in a neighbourhood of a city. Therefore, each step of the framework is described with the corresponding stage of the project. In the case such a power plant is characterized by a positive assessment, floating PVs can be proposed as a valuable socio-technical system to contribute to achieving sustainable energy development in cities so that the third sub-question can be answered. Also, this decision-support framework can be a preliminary tool to go towards the development of a universally recognized framework for the sustainability assessment of floating PV plants in cities.

4.1 PLANNING

A floating PV energy project starts with the planning stage. The objective of this stage is to select a suitable location for the energy system considered. Therefore, the political, economic, social, and physical features of the location are analysed to evaluate its suitability. Next, the characteristics of the power plant components are specified. The information collected from the selection and specification of the location and energy system's components is used to define specific goals to be achieved in accordance with the SDGs principles. Therefore, the first three steps of the framework must be carried out during this stage of the energy project.

4.1.1 SELECTION AND SPECIFICATION OF THE LOCATION

Being a nation with a population density of around 500 individuals per Km^2, the Netherlands is a highly populated country (Statista, Statista Research Department, 2019). In addition, in 2019, almost 92% of the total population of the country lived in cities (Statista, Statista Research Department, 2019). Also, in the Netherlands, residential neighbourhoods consume 30% of the total energy in a city and are mainly powered by natural gas (Ryan & Trudgeon, 2015). Finally, since the Dutch nation has a land area of 33480 Km^2 and that half of it is used for agriculture and farmland, space management and optimization became central issues for the government (Group W. B., 2019). There are 52,000 hectares of shallow inland waterways across the Netherlands, offering a significant untapped potential for integrating floating solar panels into existing landscapes (Isabella & Ziar, 2018). The Friesland province is one of the leading Dutch regions when it comes to the implementation of SETs. As a matter of fact, to achieve sustainable energy development, the provincial government set clear targets to be met and put in place policies and programmes to support an integrated implementation of renewable energy systems on a local scale. Leeuwarden is the capital city of Friesland and aims to generate more energy from local renewable energy sources (Ryan & Trudgeon, 2015). The city council has the goal to make the overall energy supply fully independent from fossil fuels by the year 2030 (Ryan & Trudgeon, 2015). In addition, the municipality is committed to promoting sustainable development in the city by achieving the 2030 SDGs' objectives. These ambitions have led to a technical decentralization of energy production focused on implementing energy systems to provide clean electricity to buildings and neighbourhoods (Ryan & Trudgeon, 2015). Given the presence of a regional and local commitment towards the energy transition and numerous inland water bodies, Leeuwarden is the perfect municipality to develop a case-study for this research project.

Therefore, Google Earth is used to select a neighbourhood in the city and a specific location for the installation. After a digital geospatial analysis focused on residential areas within the municipality boundaries, the Camminghaburen district located on the northeast edge of Leeuwarden is selected (Figure 12). To evaluate whether this place is suitable for the installation of a floating PV system, online research is done to collect information related to the political and socio-economic conditions of the district.

Figure 12: Screenshot from Google Earth showing the location of the Camminghaburen neighbourhood in Leeuwarden.

Camminghaburen was created in the 1980s as a green new-build residential area. It is the largest neighbourhood of the city in terms of area (249 hectares) and the number of residents (11500 in 2020) (Charts.info, 2021). It is a culturally diverse area where many young families from different layers of society live. Camminghaburen is locally known for being one of the two areas of Leeuwarden where a district heating system (DHS) powered by natural gas is in place (Ng, 2019). Such a system is one of the main sources of CO_2 within the town boundaries. Also, natural gas is used as the main source of electricity. The municipality of Leeuwarden showed commitment to make the DHS more sustainable and diversify the sources of electricity for the residents. In fact, in 2015, a collaboration with the Frisian government started to improve the efficiency of the DHS and increasing the number of solar energy systems in the neighbourhood. To incentivize the realization of these energy projects, the regional government implemented policies aimed at reducing CO_2 emissions and financially support PV installations. Therefore, policy instruments like CO_2 emissions taxation and subsidies (30% of the capital costs are usually covered by public institutions) are in place to achieve these ambitions (Dijkman, 2016). This political condition allowed the DHS to be upgraded in a way that forty-thousand tons of CO_2 are saved in 30 years. In addition, it boosted the development of several stand-alone PV systems applied on the rooftop of many houses of the neighbourhood (Dijkman, 2016). This is confirmed by doing a spatial analysis with Google Earth. It is thus reasonable to affirm that there are political requirements to investigate the implementation of a floating PV in the urban area. In addition, this indicates that some of the inhabitants of the area are experiencing the socio-economic conditions to accept and invest in solar energy. However, further analysis is needed to evaluate the economic suitability of the location. By doing online research, data from the housing market of the district are collected. Interestingly, the data suggest that the average price of a house in Camminghaburen is higher than the one in the whole city of Leeuwarden. In fact, as of March 2021, a house in the area selected cost on average 218300€, while the average of the city in the same month was 205000€. This indicates that the quality of life of the district is above the town average. Furthermore, information related to the average income of the neighbourhood is collected online. According to a database from the Dutch Regional Data website, the average yearly income of a Camminghaburen resident in 2020 was 33000€, which is just below the national average of 35000€ (Funda, 2020). These data suggest that, overall, the inhabitants of the location selected are wealthy and experience stable economic conditions. Therefore, it is reasonable to say that they could financially support the implementation of a floating PV system.

Finally, web research is done to investigate how the neighbourhood is managed. It is thus identified the Multifunctional Centre Camminghastins (MFC). This is a public institution that operates as the control base of the district to deal with local issues. The MFC is managed by the inhabitants of Camminghaburen. This created a strong sense of community between the residents, as local people can report problems and participate during decision-making processes. The MFC has an official website (https://www.camminghaburen.nl/) which is updated daily to inform inhabitants of events, private and public initiatives, and other issues that can promote local sustainable development. The MFC can thus be used as a communication mean to integrate the people of Camminghaburen during the development stages of the energy project. In addition, there are two official Facebook groups of the neighbourhood, namely Camminghaburen Leeuwarden and Wijk Camminghaburen. More than 3500 people follow the groups; therefore, they can also be used to communicate with the residents of the area.

Next, the physical suitability of a specific location is evaluated. Centrally located in the neighbourhood is Kronenberger Park, a green zone created as a cultural and leisure space of the district. The Park includes a football cage, a basketball court, and works of art, such as the Porta Fortuna inspired by an old amphitheatre. More importantly, Kronenberger Park faces the largest intersections of canals within the built environment of the city (Figure 13). This feature makes this location potentially suitable for the installation of a floating PV system. By analysing the area through Google Earth, on-site observations, and SketchUp Pro 2021, this location is further examined to understand whether it meets the criteria mentioned in the methodology.

Figure 13: Screenshot from Google Earth showing Camminghaburen neighbourhood, Kronenberger Park, and the large intersection of canals, which correspond to the area selected for the installation of the floating PV system.

With Google Earth, the presence of a water body in the neighbourhood is thus confirmed. The dimension of the area considered (enclosed by the red line in Figure 13) is measured with Google Earth, using the measurement command. The result is an area of ten-thousands square meters (10000 m^2), which is a space large enough for the installation of a floating solar plant (Figure 14). Furthermore, the maximum depth of the canal in the area selected is four metres and the water level does not change substantially throughout the year (Ryan & Trudgeon, 2015). This will prevent the installation of the floating system from being expensive and technically challenging (Silva & Branco, 2018). Subsequently, the 3-D feature of Google Earth is used to visually observe the elements that surround the canal. It is thus noted that there are two six storey buildings at west and south-west of the canal. In addition, along the south coast of the canal, there is a long line of trees of small and medium heights. Similarly, at south-west small trees are present. The elements that surround the canal at north are low houses and bushes along the coast. Finally, at south-east there is Kronenberger Park and some more trees of small-medium heights.

Figure 14: Screenshot from Google Earth showing a close-up of the location considered, so that the elements that surround the canal can be seen.

To evaluate the accuracy of Google Earth, an on-site empirical analysis is carried out. One visit at the location was enough to confirm that the buildings and trees identified with the geospatial online platform are realistically reported. In fact, by walking around the area while interacting with the Google Earth application opened on the phone, the presence of every relevant element that surrounds the canal was validated. Furthermore, on-site analysis was focused on visualizing the shading patterns of the elements around the canal to observe how much water surface they cover. Since the Netherlands is in the northern hemisphere, the PV panels will be oriented towards south, as sunlight arrives from that direction. Therefore, only the shading of the south, south-east, and south-west elements is analysed. The location is thus visited two more times, once during sunrise and the other during sunset, to observe the shading of the trees and the building highlighted in Figure 15.

Figure 15: Screenshot from Google Earth showing the elements whose shading patterns are empirically and digitally analysed during sunrise and sunset.

The two visits were done on the same day, precisely on 15/5/2021, during spring. The weather was sunny throughout the day so that it was possible to observe the shadings patterns of the elements considered. The empirical analysis in the morning is carried out from 6:00 AM to 10:30 AM. At 10:30 AM it was clear that most of the area selected was free from any shading, meaning that it would not be covered until evening. Therefore, the morning investigation was stopped, as no additional data were needed. The evening analysis was done from 5:00 PM to 9:30 PM when the sun was not visible anymore. The data generated are qualitatively information noted in a notebook while observing the shading patterns. To support the findings of this empirical examination, SketchUp Pro 2021 is used to develop a 3-D digital model of the location selected and carry out a digital shading analysis (Figure 16). The data collected from the on-site investigation are thus combined with those generated from the digital analysis to produce reliable information regarding the amount of shading that the canal receives. As a result, the technical suitability of the location considered is evaluated.

Figure 16: Digital 3-D model of the location in the Camminghaburen neighbourhood develop with SketchUp Pro 2021. This model is used to carry out an automatic shading analysis.

The model is created by using the import location command of SketchUp. This allows the software to automatically develop a digital copy of the area that includes the topography and main components, i.e., buildings and trees. Therefore, the shading analysis command is used to visualize the shading of the trees and buildings throughout a day of spring. The qualitative data generated from the on-site visits and digital shading analysis are summarized in Tables 3 and 4. Hourly observations are reported to have details of the shading patterns during the time ranges considered.

SUNRISE

15/5/2021 TIME:AM	6:00	7:00	8:00	9:00	10:00
OBSERVATION	Shading from the south-east elements is weak; but covers most of the water surface of the	Shading from the south-east elements intensifies but starts to retreat. However, shading still	Shading from the south-east elements is now clearly visible but covers around a quarter of the	Shading from the south-east elements is now neglectable; but elements from south	Shading from the south elements covers a neglectable portion of the south coast;

	canal. The shading comes only from the trees in Kronenberger Park.	covers around half of the area selected. The shading comes only from the trees in Kronenberger Park.	area selected. The shading comes only from the trees in Kronenberger Park.	start to shade a small portion of the area, in front of the basketball court. The shading comes from the line of trees south of the canal.	most of the area is free from shading.

Table 3: Hourly observations generated during morning shading analysis. The Sun rises from south-east and the shading it produces on the water surface is analysed until it becomes neglectable.

SUNSET

15/5/2021 TIME:PM	5:00	6:00	7:00	8:00	9:00	9:30
OBSERVATION	Shading does not cover any portion of the area selected.	Shading does not cover any portion of the area selected.	Shading from south and southwest elements start to cover portions of the water surface close to the south coast. However, the amount of surface covered remains neglectable.	Shading from the south elements does not cover the area anymore. However, shading from the southwest and west elements is now covering a quarter of the area selected. The shading comes from the two six-storey	Shading from south-west elements covers half of the area considered. The shading comes from the two six-storey buildings and trees.	Shading is not present anymore, as sunlight is too weak to produce it. The sun is about to set.

				buildings and trees.		

Table 4: Hourly observations generated during the evening shading analysis. The Sun sets at south-west and the shading it produces on the water surface is analysed until it becomes neglectable.

This analysis allows us to investigate the daily shading patterns of the elements south of the canal. The data generated suggest that the area selected for the installation receives a substantial amount of sunlight throughout the day. As a matter of fact, during spring, the area is entirely free from any shading from 10:00 to 7:00 PM. This means that, on a sunny day of spring, the whole 10000 m^2 selected receives 9 hours of direct sunlight, making it a physically suitable location for the installation of a floating PV system. By generating and analysing these data and information, the political, socio-economic, and physical suitability of the location selected is confirmed and the selection of the system's components can start.

4.1.2 SELECTION AND SPECIFICATION OF THE FLOATING PV SYSTEM

The selection and specification of the floating PV plant start by defining the floating system and its components. Subsequently, the PV module selected is illustrated, to conclude with a 3-D model of a floating PV solar unit that will be deployed for this energy project. The criteria to respect during this step are choosing the elements of the power plant while keeping low costs, ensuring safety and operation over time, and optimizing efficiency.

The physical characteristics of the floating system components are selected by reviewing online reports and the company's websites. The floating device that supports the PV modules is inspired by the structure of small pontoon boats. A digital 3-D model of the floating pontoon structure is shown in Figure 17. The model was developed with SketchUp Pro 2021.

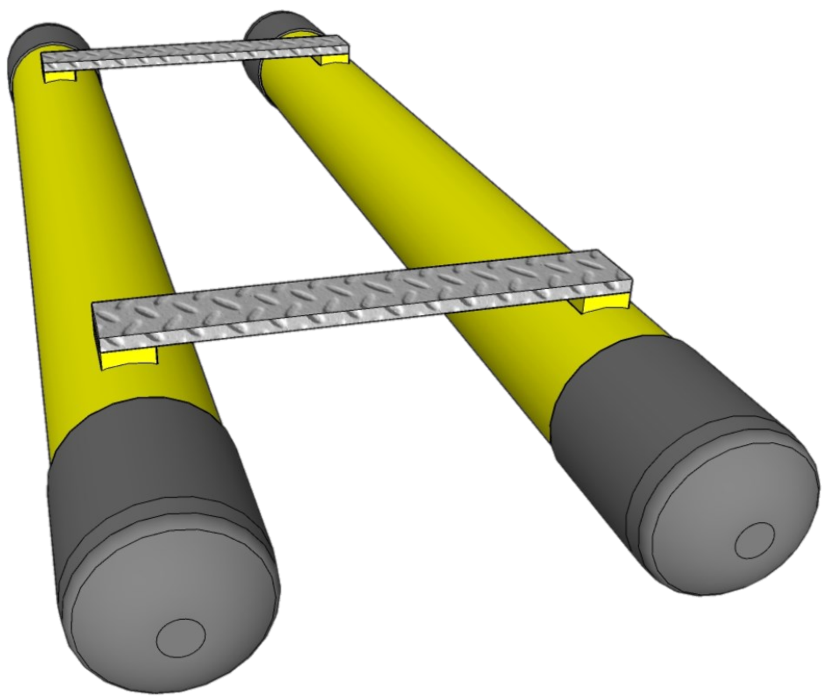

Figure 17: The structure of the pontoon to sustain two PV arrays. Such a structure consists of two long pipes for floating pontoons parallel to each other and connected by an aluminium frame coated with water-resistant paint.

Due to its simple and effective design, this type of floating technology is widely used to sustain solar panels installed on inland water bodies. The buoyancy of the pontoon structure must be able to support the weight of the PV panels without being submerged. The ideal material to provide this property is high-density polyethylene (HDPE). As a matter of fact, HDPE density is about 96% of that for freshwater, and about 94% that for saltwater, enabling the pontoon to sustain more than a ton without losing buoyancy. In addition, this material is UV-resistant, corrosion-resistant, and has a high tensile strength (Kreiter, 2017). The flexibility of HDPE allows it to adapt to water environments without the need for expensive foundations. Also, the high-stress capacity of these floating devices allows a pipeline to safely shift or bend to accommodate itself to motion that can result from strong waves and current actions. Furthermore, HDPE allows manufacturing light wight pipes that can easily be assembled on-site (Kreiter, 2017). As a result, the costs of such a pontoon structure are maintained low while the safety and efficiency of the floating system are optimized. Furthermore, polyethylene pipes are surprisingly resilient and resistant to damage caused by external loads, vibrations, and other adverse conditions including extremely cold weather. In the Netherlands, HDPE pipes for floating systems are manufactured by BIS Floats (https://www.bisfloats.nl/). Therefore, for this project, it is suggested to purchase the pontoon shown in Figure 17 from the company BIS floats.

The next components to be selected for the floating PV plant are the mooring and anchoring systems. The mooring system connects with underwater cables the anchors to the HDPE floating device, forming a permanent structure that is used to prevent pontoons from moving and rotate. Since the maximum depth of area selected is 4 metres, positioning the anchoring devices at the bottom of the canal should not be a technical challenge. This project uses the technology manufactured by SEAFLEX to create an eco-friendly and effective mooring system (https://www.seaflex.com/applications/solar/) (Figure 18). Finally, the anchors should be provided by the company Ciel & Terre (https://www.ciel-et-terre.net/hydrelio-floating-solar-technology/anchoring-systems/).

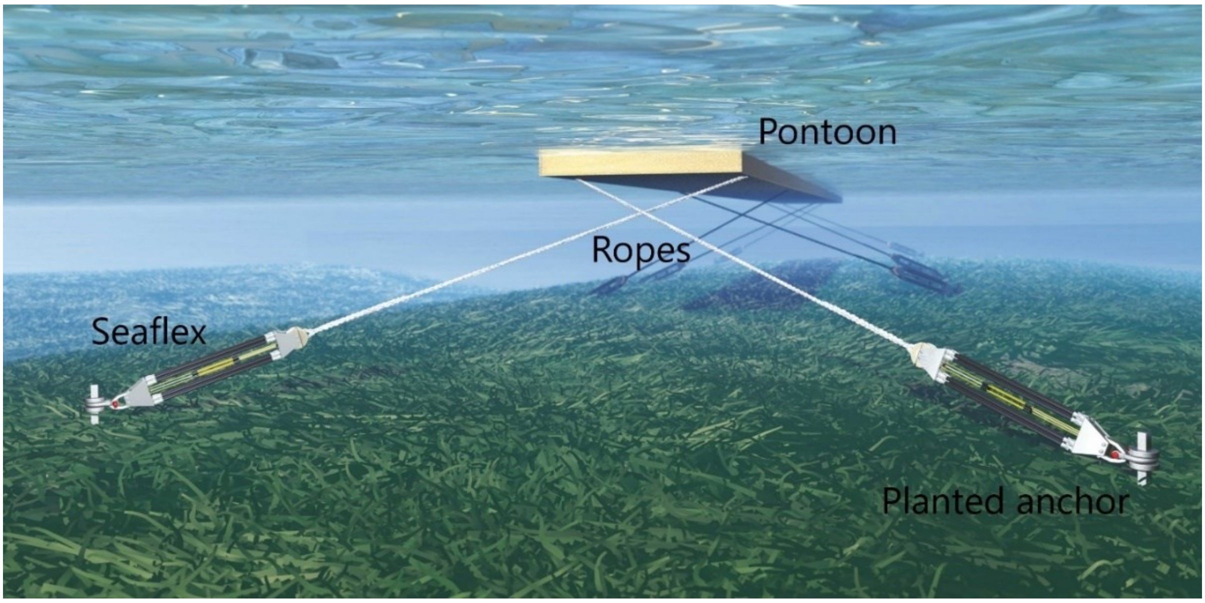

Figure 18: The mooring and anchoring system selected for this project. The seaflex device is used as a flexible connector to link the anchors with the ropes. It makes sure that the concrete blocks planted in the seabed do not move. Metals bolts are used to connect the end of the seaflex with the anchors (https://www.seaflex.com/applications/solar/).

Such a system consists of planting a concrete block beneath the seabed and connecting it to the pontoon using nylon wire ropes. The use of nylon wires avoids any issue related to corrosion of the mooring system and ensures strength and flexibility to the connection. By positioning the concrete blocks under the seabed, the anchors do not directly interfere with the surrounding ecosystem and ensure stability to the pontoons. In addition, SEAFLEX technologies use a flexible plastic connector to link the anchors with the nylon ropes. Such a device prevents the anchors from being under pressure during movements of the floating pipes so that the concrete blocks can remain in the same place over time. In conclusion, by selecting these technologies for the floating system, costs can be maintained low, and the correct operation of the plant optimized throughout time so that the technical criteria are met.

The next phase consists of selecting and specifying the solar PV technology via literature and reports reviews. The main criteria to be met during this phase is to maintain reasonably low costs and optimize the efficiency of the panel. For the inverter, it is proposed a model manufactured by the company Generic. The model is PVS800-57-0100kW-A and has a conversion efficiency of 90%-91% (Inversters, 2012). In this project, bifacial panels are used as PV technology for the power plant. The specific panel that is proposed for the floating installation is the GCL-P6/60GDF-250 bifacial polycrystalline module. Such technology is manufactured by the GCL System Integration company (https://www.gclsi.com/). The nominal power of a unit is 250 Watt-peak and has an efficiency of 30%. Bifacial panels are more expansive than conventional ones, but polycrystalline are cheaper than monocrystalline. This trade-off prevents the costs of the modules from being too high. In addition, its efficiency is optimal for a polycrystalline panel. The dimensions of a single unit are 1,64x0,99x0,035m and its weight is 15 Kg. The expected lifetime of these PVs is 30 years with a warranty of 10 years. Since the location selected is in the northern hemisphere, the panels must face south. Being in the Netherlands, the ideal tilt of each module is 37° (B.Parida, S.Iniyan, & R.Goic, 2011). Finally, a lightweight aluminium frame is attached to the pontoon to support the PV panel and maintain it at a height of three metres above the water (Group B. S., 2018).

These components are now combined to develop a digital 3-D model of a floating PV solar unit using SketchUp Pro 2021 (Figure 19). Therefore, the model of the pontoon is combined with PV modules. Since the pontoon can sustain more than 1 ton, two PV arrays, each with 24 panels, are attached to it. The weight of the two arrays is thus 720 Kg, plus the weight of the aluminium frames, which is approximately 50 Kg in total. As a result, the pontoon will be able to sustain the two arrays without losing buoyancy. In addition, by digitally analyse the shading patterns of the PV arrays with SketchUp, it is possible to design the unit in a way that the panels are not covered by shading throughout the day. In this way, efficiency can be optimized. The distance between the panels, the length of the floating pipes, and the dimensions of the array are illustrated in Figure 19.

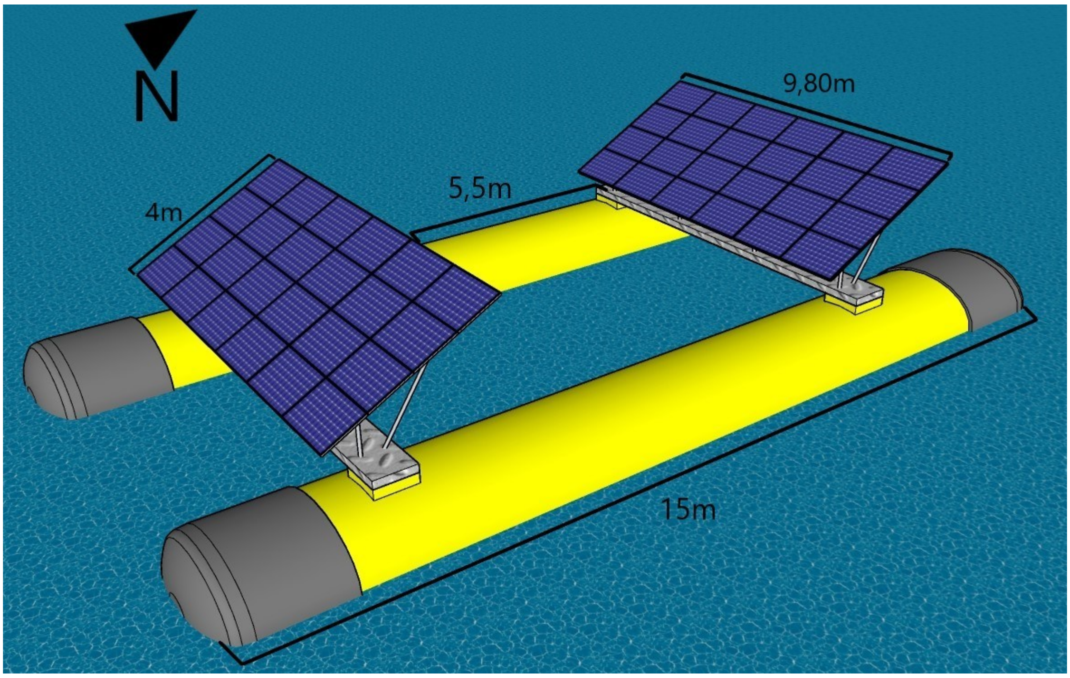

Figure 19: Digital 3-D model of a floating PV solar unit, consisting of two arrays and the pontoon system. Each of the arrays has 6x4 panels. Therefore, their dimensions are 9,80x4m. The spacing between the arrays is 5,5m, while the length of the pipe is 15m.

Finally, the nominal power of one array can be calculated by multiplying the Watt-peak (Wp) of one panel by the number of modules. The result is 6000 Wp, or 6 kWp, meaning that one floating PV unit has a nominal power of 12 kWp.

The first two steps of the decision-support framework are now completed. The political, socio-economic, physical, and technical suitability of the location and the components have been evaluated and confirmed. Therefore, the Camminghaburen neighbourhood in Leeuwarden and the specific area selected are the ideal locations to further investigate the sustainability of floating PVs in urban areas. In addition, during this step of the framework, a floating PV solar unit consisting of a pontoon and two 6 kWp PV arrays has been designed and its characteristics described. This knowledge is now combined with the principles of the three SDGs objectives to define the goals sought to be achieved.

4.1.3 DEFINITION OF GOALS

According to SDGs 7, 11, and 13, sustainable energy development in an urban area requires technical considerations, economic growth, social inclusion and participation, and environmental protection and enhancement. The definition of goals is based on the objectives of the United Nation's SDGs 7, 11, and 13. In addition, the characteristics of the location and the energy system previously specified are integrated with such definitions. Therefore, the goals are categorized as objectives sought to be achieved within the scopes of the three SDGs described in the theoretical framework.

- Affordable and clean energy (SDG 7) related goals for Camminghaburen:
    - The energy and economic performance of the floating PV system must be optimized.
    - The floating PV system must generate clean energy for the households of Camminghaburen.
    - The floating PV system must generate affordable energy for the households of Camminghaburen.
    - The floating PV system must contribute to diversifying the energy mix of the neighbourhood.
- Sustainable cities and communities (SDG 11) related goals for Camminghaburen:
    - The development of the floating PV system must be characterized by the participation and inclusion of Camminghaburen residents in the decision-making processes.
    - The floating PV system must be socially acceptable for the residents of Camminghaburen.
    - The floating PV system must create jobs and boost the economy of the neighbourhood and the city.
    - The floating PV system must not hinder economic or leisure activities that depend on the availability of the canal.
    - The floating PV system must not generate negative environmental effects on the canal, Kronenberger Park, and the surrounding area.
- Climate action (SDG 13) related goals for Camminghaburen:
    - The floating PV system must contribute to reducing the CO_2 emissions within the neighbourhood and the city.

With the definition of specific goals, the planning stage of this fictional energy project is completed, and the evaluation of the construction activities can start.

4.2 CONSTRUCTION

The construction stage starts with the identification of the sustainability indicators related to the installation works. During this stage, it is important to manage the activities in a way that the efficiency of the energy system is optimized while generating minimal negative effects. The indicators identified for this stage are analysed and used to assess whether the installation activities of a floating PV system in a neighbourhood can be implemented sustainably. Therefore, once they are identified, indicators are evaluated to generate technical, environmental, economic, and social data and information to be assessed. As a result, this development stage concerns the fourth, i.e., identification of indicators, and fifth, i.e., evaluation of indicators, steps of the decision-support framework.

4.2.1 IDENTIFICATION OF INDICATORS

The indicators identified from literature and reports necessary to assess the sustainability of the construction activities are categorized by the four sustainability dimensions.

4.2.1.1 Technical indicators

The technical indicators that concern the installation of the floating PV system include five aspects that are related to managing the technicalities of the construction activities. The analysis of these indicators is important to evaluate how the energy system can operate at optimum performance. These are:

- **Shading patterns**, which refer to analysing the shading of the floating PV system, to determine the spacing between arrays and optimize the use of the area available. In addition, this indicator consists of analysing the shading patterns of the elements surrounding the canal and the floating PV system to visualize how they interact so that the sizing and positioning can be defined (Extebarria, 2018).
- **Position of the floating PV units on the canal**, which is analysed to make sure that the arrays do not hinder the passage of boats in the area selected (Apribowo, Suyitno, Santoso, & Wicaksono, 2019).
- **Size of the floating PV system**, which means specifying the number of arrays and other components in the system (Sen, 2015).
- **Area occupied by the system**, to define the spatial boundaries of the installation works (Durkovic & Durisic, 2017).
- **Time of the construction activities**, to define the time boundaries of the installation works (Extebarria, 2018).

4.2.1.2 Economic indicators

The economic indicators are related to the financial management of the construction activities. Therefore, the following economic aspects and impacts are identified as the indicators:

- **Capital cost**, which refers to the fixed, one-time expenses incurred to purchase the components of the floating PV system (Afgan, Carvalho, & Hovanov, 2000).
- **Financing of the installation**, consisting of specifying who is going to pay for what during construction works (Apribowo, Suyitno, Santoso, & Wicaksono, 2019).
- **Local economic acceptance**, namely the willingness of the residents to pay for the installation of the floating PV system (Afgan, Carvalho, & Hovanov, 2000).
- **Job creation**, which consists of describing the types of jobs that the construction works will create (Bond, Morrison-Saunders, & Pope, 2012).
- **Local business interferences**, which consist of considering what type of businesses could be negatively affected by the construction works (Fiksel, Eason, & Frederickson, 2012).

4.2.1.3 Environmental indicators

The environmental indicators are related to the environmental aspects and impacts of the floating PV system construction works. Five indicators are identified for this dimension of sustainability. These are:

- **System life cycle CO_2 emissions**, to estimate the CO_2 emissions from manufacturing each group of components (Santoyo-Castelazo & Azapagic, 2014).
- **Water, air, and soil pollution**, which refers to the release of unwanted substances in the aquatic, aerial, and terrestrial environment (Tawalbeh, et al., 2021).
- **Noise pollution**, consisting of considering the possible sources of noises that could disrupt the biological cycle of fauna (Afgan, Carvalho, & Hovanov, 2000).
- **Ecosystem disruption**, which refers to any activity that may disrupt the aquatic, aerial, and terrestrial ecosystems (Bond, Morrison-Saunders, & Pope, 2012).

4.2.1.4 Social indicators

Finally, the social indicators related to social aspects and impacts of the construction activities are identified. These are:

- **Social participation in the decision-making process**, to evaluate how residents can be included to decide whether the installation of the floating PV system should be carried out (Santoyo-Castelazo & Azapagic, 2014).
- **Local social acceptance**, which refers to the level of acceptance of the Camminghaburen residents toward the installation of a floating PV system in their neighbourhood (Boon & Dieperink, 2014).
- **Local leisure activities interferences**, to assess whether the floating PV system would hinder the fulfillment of any social activity (Fiksel, Eason, & Frederickson, 2012).
- **Noise pollution**, which consists of considering the possible sources of noise that could disturb the livelihood of the inhabitants and workers (Fiksel, Eason, & Frederickson, 2012).

These are the technical, economic, environmental, and social sustainability indicators to be evaluated for the construction stage of a floating PV system energy project. The evaluation step is now carried out.

4.2.2 EVALUATION OF INDICATORS

The evaluation of the sustainability indicators identified consists of using different measurement and processing methods to generate the data and information necessary for the assessment of the construction activities. The indicators are categorized by the four dimensions of the decision-support framework and individually evaluated.

4.2.2.1 Technical indicators

To evaluate the technical indicators related to the construction stage SketchUp Pro 2021 and literature and reports review are used. Therefore, a 3-D digital model of the floating PV system is developed, and its shading patterns analysed to determine the spacing between arrays. Subsequently, this digital system is imported into the model of the location previously created to analyse how the shading patterns of the elements and the PV system interact.

- **Shading patterns**.

To evaluate this indicator the topography of the area selected for the installation, i.e., 10000 m^2, is imported in SketchUp and filled with as many floating PV solar units as possible. By digitally analysing the shading patterns of the arrays, it is possible to determine the ideal spacing between each floating unit, so that the position of the system can be clarified (Figure 20). In this way, losses due to shading cover are minimized and efficiency optimized. Several floating units are assembled to form long lines of arrays. Each line is parallel to the other and distanced 10 metres. The vertical spacing between the arrays is maintained at 5,5 metres. This allows to optimize the use of the available area and to propose a preliminary vision of the system. However, further analysis of the shading patterns is necessary to finalize the actual size of the power plant.

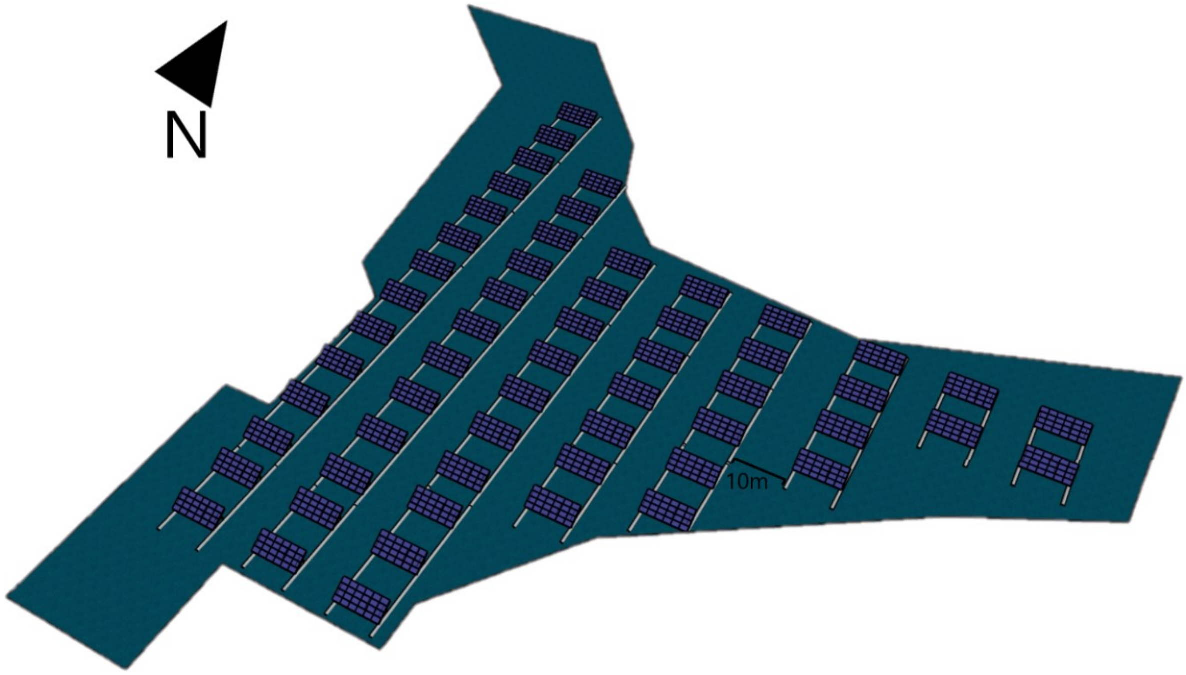

Figure 20: Digital 3-D model of the preliminary floating PV system. The spacing between the lines of the parallel array is 10 metres.

The shading analysis continues to understand how shading patterns of the elements that surround the canal interact with the floating PV system proposed in Figure 20. Such a visual analysis is done to understand which floating PV arrays are subject to shading losses throughout the day. Therefore, a 3-D model that combines the floating system with the location considered is developed (Figure 21). The arrays subject to shading are highlighted with a red point and are mainly focused on the south, south-west, and north-west of the PV plant. This analysis helps to identify the arrays that would cause the efficiency of the system to decrease and the costs of the installation to be unnecessarily high. Therefore, they are left out of the final sizing of the system.

- **Position of the floating PV units on the canal**.

The digital 3-D model in Figure 21 also helps to visualize the positioning of the floating solar units. This evaluation is done to make sure that the panels are positioned in a way that the passage of boats in that part of the canal can happen also after the construction of the system. Therefore, the units cannot occupy the whole area selected. As a result, the north and north-east solar arrays area is also highlighted with a redpoint, meaning that they are not considered for the final sizing of the power plant (Figure 21).

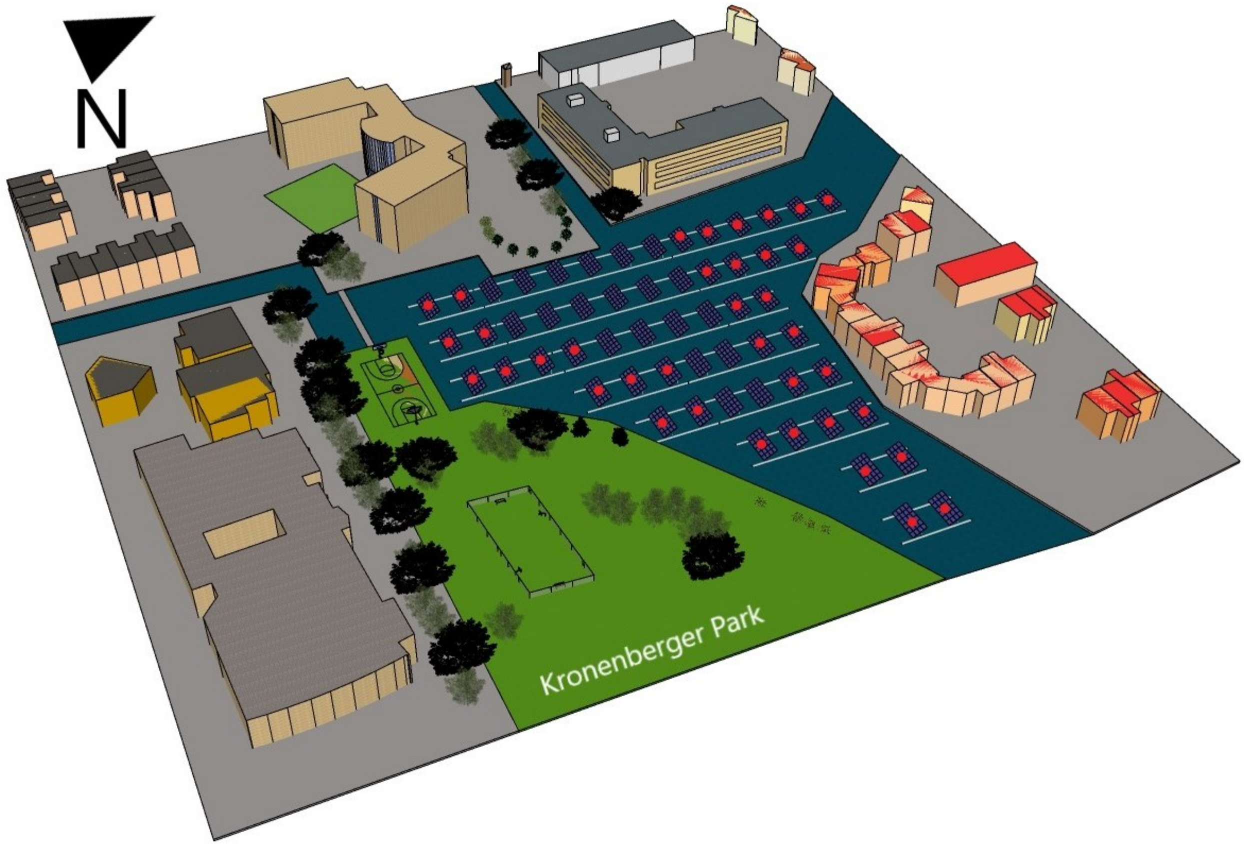

Figure 21: Digital 3-D model of the preliminary floating PV system and the location selected. The arrays that are subject to shading throughout the day and that would hinder the passage of boats are highlighted with a redpoint. They are not considered for the final sizing of the floating PV system.

- **Size of the floating PV system**.

The results of the evaluation of the two previous technical indicators show the size and final design of the floating PV plant (Figure 22). The size of the system can thus be estimated, by specifying the number of floating and underwater components and arrays. There are five parallel lines of arrays. Starting from the east, the system is composed of two single floating PV units, followed by a double solar unit and two lines of triple units. Therefore, the plant consists of 20 arrays, each with 24 panels, meaning that there are 480 PV modules in total. As a result, knowing that each array has a nominal power of 6 kWp, the nominal power of the system can be measured by multiplying the kWp and the number of arrays. Considering conversion losses due to the inverter (9-10%), the result is 110 kWp.

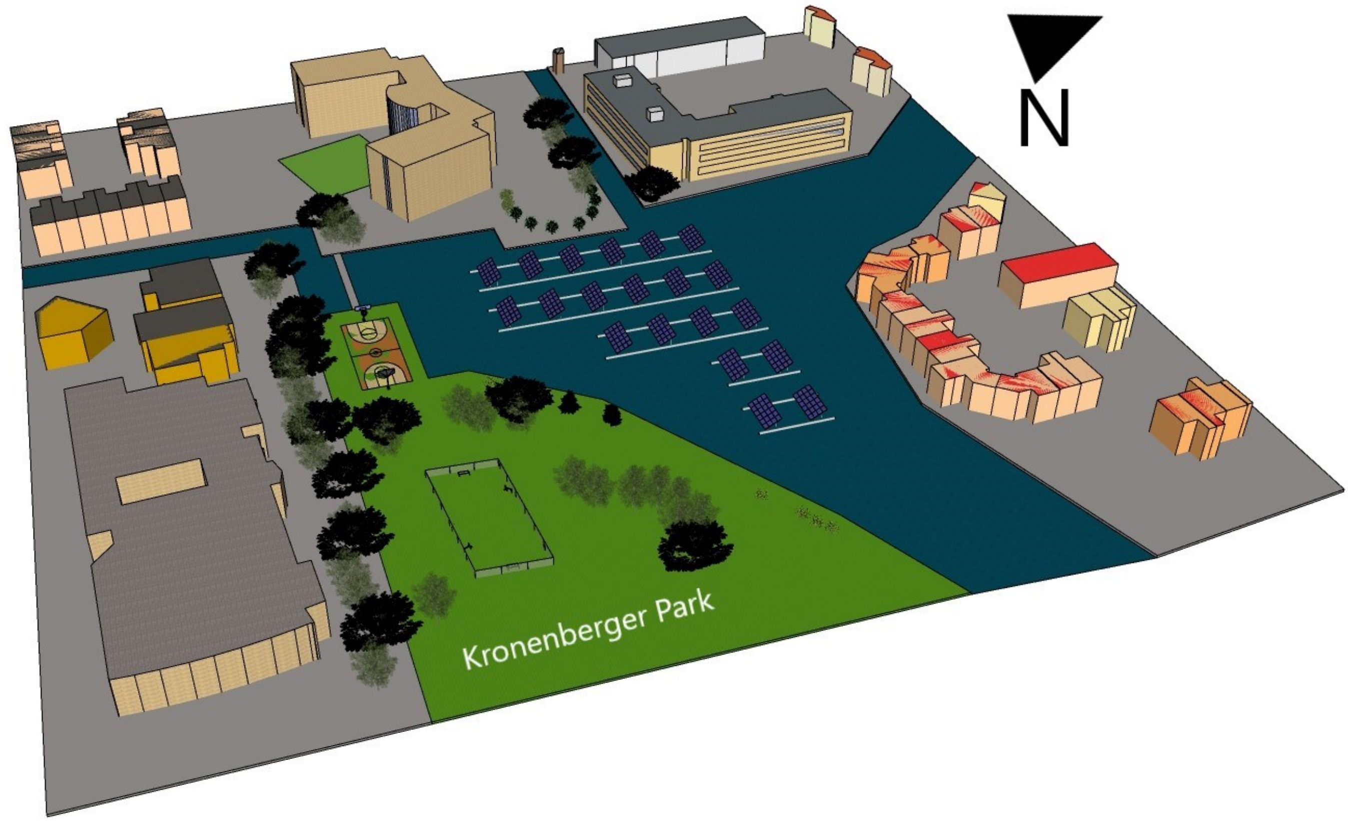

Figure 22: Digital 3-D model of the floating PV system final design installed on the canal in Camminghaburen. The number of arrays and their position in the canal are clearly visible. This design should enable boats to use the canal also after the installation of the solar plant. At the same time, the precise position of the arrays allows the system to be free from any shading that could cause efficiency losses and unnecessary costs.

From this, the quantity of each component that forms the floating system can be specified. Since there are 20 arrays, as many aluminium frames are needed to support the panels on the pontoon. The 20 arrays are positioned on 10 pontoons units, which are connected by 10 mooring systems to the anchors. Finally, 40 anchors are needed to stabilize the floating panels.

- **Area occupied by the system**.

The total area that the final design of the floating PV system is measured using SketchUp. The result of this digital spatial analysis shows that the area occupied by the plant is equal to 4500 m^2, which is substantially smaller than the one previously selected of 10000 m^2.

- **Time of the construction activities**.

The time necessary to carry out the construction stage is estimated from a reports review. According to the company Ciel & Terre, a floating PV system with a nominal power of 1 MWp takes 6 months to be installed (Terre, 2017). By considering that the solar plant on the canal in Camminghaburen has a nominal power of 110 kWp, it is possible to approximate the construction time of this energy project, which should be around a tenth of 6 months (Terre, 2017). This means that the floating PV system design should take no more than 20 days to be installed, which is a remarkably short period.

4.2.2.2 Economic indicators

To evaluate the economic indicators related to the construction activities the software PVsyst 7.2 is used. Such software enables engineers to use inputs like the specific type of PV technology, the type of inverter, and the number of panels to simulate the installation costs of the energy system. Therefore, the software can process such inputs and automatically provide data that describe the capital costs of the system. However, literature and reports are also used to analyse the indicators that the software cannot simulate. In addition, a survey is proposed to the residents to evaluate the local willingness to pay for the floating PV system. Therefore, capital costs and financing of the installation are analysed using PVsyst 7.2, while job creation and local business interferences are analysed with literature and reports.

- **Capital cost**.

To evaluate the fixed, one-time expenses incurred to purchase the components, three inputs of data are entered in the software PVsyst 7.2. These are the type of PV panel, namely GCL-P6/60 bifacial polycrystalline module, the number of panels, namely 480, and the type of PV inverter, PVS800-57-0100kW-A. The software can automatically measure the costs of the panels and the inverter using an online database. However, the costs of the floating system components, silver and aluminium are collected from the websites of the companies that manufacture them. The results of the capital costs incurred in the construction works are thus summarized in Table 5.

	Item	Quantity units	Cost €	Total €
PV modules				
	GCL-P6/60GDF-265	480	95.00	45600.00
	Aluminium support frames	20	15.00	300.00
	Silver	9,6 Kg	717	6883
Inverter				
	PVS800-57-0100kW-A	1	5000.00	5000.00
Other components				
	Pontoon	10	200.00	2000.00
	Mooring system	10	100.00	1000.00

	Anchors	40	30.00	1200.00
	Wiring	1	5000.00	5000.00
TOTAL				66983.00

Table 5: Summary of the capital costs incurred in the construction of the floating PV system.

The total capital cost is equal to 66983.00€. Each panel costs 95.00€ and the aluminium frame that supports it costs 15.00€. The system has one inverter, which costs 5000.00€. The rest of the expenses are dedicated to the floating system components and are equal to 9200.00€, which is approximately 15% of the total costs. It is now important to analyse how this cost is managed to enable the installation activities to start.

- **Financing of the installation**.

This indicator is evaluated by researching online for the most recent data related to the financial management of solar energy projects in the nation. In the Netherlands, the national and regional governments collaborate to guarantee financial support for the implementation of SETs. In 2019, 30% of the capital cost of solar energy projects was covered by public institutions (Dijkman, 2016). Therefore, at least 20000.00€ should come from the financial support of governmental subsidies. The rest of the expenses, namely 46983.00€, must be covered by either private companies or the residents of Camminghaburen. To understand whether the inhabitants of the neighbourhood would pay for these costs, the local economic acceptance must be analysed.

- **Local economic acceptance**.

To determine whether residents of Camminghaburen would be interested to invest in the installation of the system, a survey is proposed. The respondents must express their level of agreement with some statements through a 5-points scale answers. 32 responses were collected from the residents of the neighbourhood in 45 days. To start, the survey proposes two statements that explore the general economic perception of solar energy. The statements and the responses are shown in Figure 23. The results show that the majority of the responses are aware of the possible economic benefit of solar energy. In fact, 23 people indicated that they either strongly agree or agree with the fact that PV solar energy can help them to reduce their electricity bills. Only 7 residents think that PV panels would not economically help them, while only 2 neither agreed nor disagreed with this statement. Nevertheless, the results of the second statement show that most of the respondents consider PV panels too expensive. As a matter of fact, 20 of them either strongly agree or agree with the fact that PVs are much too expensive to be installed for the houses. On the other hand, only 12 residents out of 32 disagreed with such a statement.

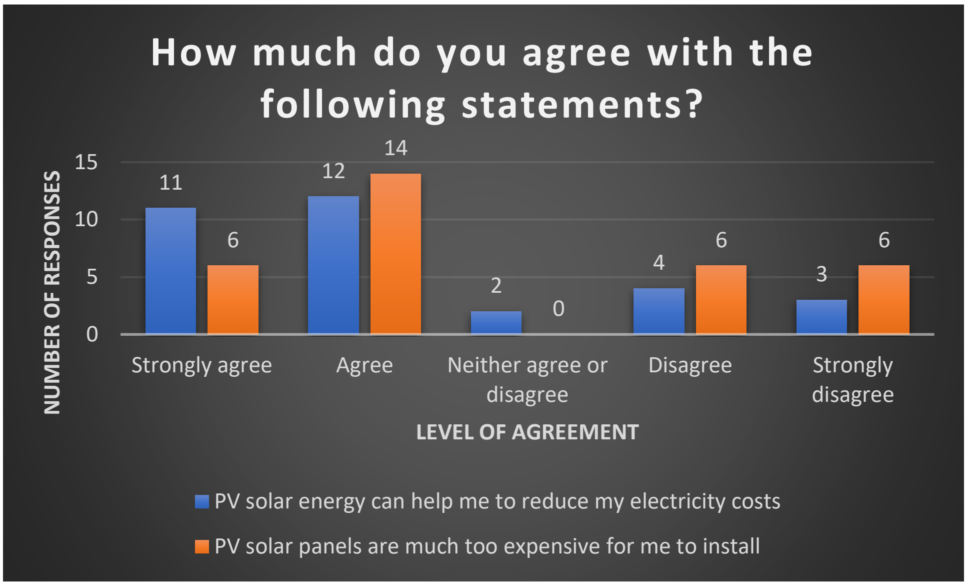

Figure 23: Histogram showing the level of agreement with the first two statements of the survey.

Subsequently, in the survey it is explained that in the case the residents decided to pay for the construction of the floating PV system, they would gain a periodical profit from it once the installation costs are paid back. On the other hand, if they decided not to invest in the solar plant, private companies would pay for the installation and gain profit from it. Therefore, four more statements are proposed. These are shown in Figure 24 with the corresponding answers of the residents.

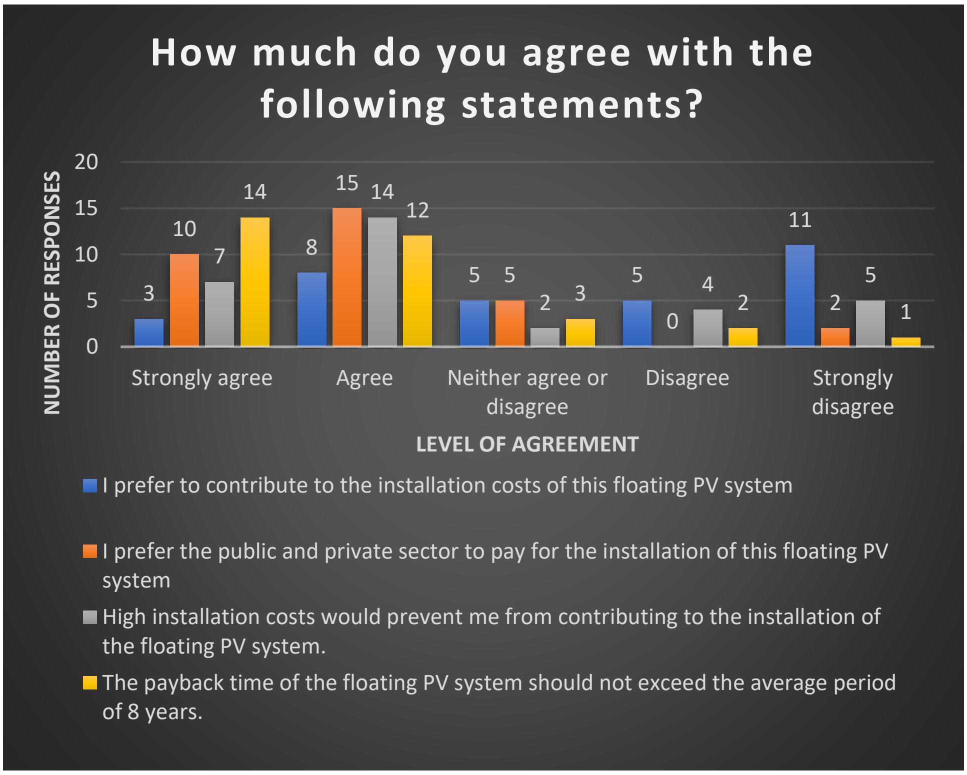

Figure 24: Histogram showing the responses of the survey used to analyse the local willingness to pay for the installation of a floating PV system in Camminghaburen.

By analysing the results of the survey, it is clear that most of the respondents prefer the public and private sectors to pay for floating PV system installation. As a matter of fact, 25 responses either strongly agree or agree to let public and private institutions pay and economically benefit from the floating PV system. On the other hand, only 11 responses either strongly agree or agree to pay for the solar power plant. This pattern is also evident in the rest of the responses: 16 answers either disagree or strongly disagree to pay for the floating system, while only 2 responses strongly disagree on letting the public and private sector invest for its installation. In addition, most of the respondents indicated that high installation costs would prevent them from financially contributing to the construction of such a power plant. Only 9 of the 32 participants answered that this would not be a problem. Therefore, the costs of the installation of the floating PV system that is not covered by the subsidies should be financed by private and public institutions. Finally, the majority agrees on the fact that the payback time should not exceed the average period of 8 years, suggesting that gaining profit is an important aspect for the inhabitants.

- **Job creation**.

The possibility of creating jobs during the construction stage is evaluated by doing a literature review focused on reading papers and reports related to the economic benefits of solar energy. Since general estimations are carried out, this analysis goas also for the operation & decommission stage. The installation of the solar energy system is a significant source of job creation compared to conventional fossil-fuelled power plants. As a matter of fact, to generate 100 KWp of solar energy 55 to 80 workers are required. To produce the same amount of energy from a natural gas power plant only 10 workers are needed (Friedman, Jordan, & Carrese, 2011). Therefore, the floating PV system (110 kWp) is expected to generate at least 85 job opportunities. Most jobs created by the PV industry are white-collar or highly skilled craft labour, including engineers, assemblers, sales representatives, and installers. In addition, many indirect jobs are created in supporting industries, such as the extraction and production of raw materials. Statistics show that for every job created by the PV industry, between 1.8 and 2.8 jobs are generated in other sectors of the economy (Friedman, Jordan, & Carrese, 2011). As a result, assuming that 2 indirect jobs are generated for manufacturing the components of this floating system, it is estimated that approximately 170 jobs vacancies would come from the development of this energy project. Nevertheless, it is important to mention that these are approximate calculations of the real number of jobs that can be created from this project.

- **Local business interferences**.

The construction of the floating PV system in the canal selected would not directly interfere with any business that depends on that section of the canal. As a matter of fact, being at the centre of the Camminghaburen residential neighbourhood, the canal is not used by big vessels for the transportation of goods. In addition, it is not identified any local business that directly depends on the availability of that canal section to operate and gain profit. This analysis is carried out on the basis of Google Maps and on-site observations.

4.2.1.3 Environmental indicators

The environmental indicators related to the construction of the floating PV system are evaluated using PVsyst 7.2 and literature and reports review.

- **System life cycle CO_2 emissions**.

The components of a solar system require high levels of heat and other industrial processes to be manufactured (Voudoukis, 2018). Therefore, CO_2 emissions are inevitable and must be considered to estimate the system's life cycle emissions. This indicator is evaluated using PVsyst 7.2. As a matter of fact, by entering the data, i.e., type of PV panel, type of inverter, size of the PV system, aluminium frame weight, and the number of floating system components, PVsyst automatically measures the inputs using an online database and provide quantitative outputs that illustrate the life cycle CO_2 emissions of each element of the plant. The results of the measurements are shown in Table 6.

Item	Life Cycle CO_2 emissions	Quantity	Subtotal
			[$KgCO_2$]
PV modules	2036 $KgCO_2$/KWp	110 KWp	223960
Aluminium frame	2,83 $KgCO_2$/Kg	1000 Kg	2830
Inverter	281 $KgCO_2$/unit	1 unit	281
Pontoons	20,69 $KgCO_2$/unit	10 units	206,9
Mooring system	5 $KgCO_2$/unit	10 units	50
Anchors	50 $KgCO_2$/unit	40 units	2000
TOTAL			229325,9

Table 6: Estimation of the lifecycle CO_2 emissions for each component of the floating PV system.

The results of this analysis show that the total floating PV system life cycle CO_2 emissions are equal to 229,32 tons. This data will be used to evaluate the CO_2 balance of the system in the operation & decommission stage.

- **Noise pollution**.

This indicator is evaluated by doing a literature review of journal papers. Like any power generation system, the construction of a floating PV facility involves the use of vehicles, boats, and heavy machinery necessary to access the site, assemble the components, and install floating structures and PV panels. Their use results in noise disturbances, which influence the natural habitat and environment by disrupting the biological cycle of wildlife. Such a situation would be an issue for this energy project, as the site is just next to Kronenberger Park. To mitigate such a problem, novel PV projects use specialized noise barriers that surround the installation site during the construction of the energy system (B.Parida, S.Iniyan, & R.Goic, 2011). Therefore, noise barriers should be used during the construction period of the floating PVs in Camminghaburen.

- **Ecosystem disruption**.

The possibility of causing ecosystem disruption during the construction stage is evaluated by reviewing journal papers and reports. Again, the use of vehicles, boats, and heavy machinery is the main factor that may influence the terrestrial and aquatic ecosystem of the site. However, these elements can be managed in a way that is eco-friendly and minimizes their interaction with the natural habitat. To do it, it is suggested to use large platforms and electric vehicles to access the site. Also, accessing the site and assembling components in proximity to Kronenberger Park should be avoided to minimize possible effects on the ecosystem. Finally, planting the anchors beneath the bed of the canal will be the main activity to disrupt the aquatic ecosystem. In fact, they cause a temporary detrimental impact on aquatic fauna living on the bottom of the canal by the increment of suspended solids or direct contact with the anchors. Nevertheless, the long-term impacts of this process are still unknown (Terre, 2017).

4.2.1.4 Social indicators

The social indicators are evaluated using the information collected during the specification of the social features of the location, literature review, and a survey.

- **Social participation in the decision-making process**.

To analyse this indicator the social information generated while specifying the location is used. The MFC should be used as the decision-making base for this energy project. As a matter of fact, it is the place where the residents and public and private figures exchange information and perspectives regarding the issues of the Camminghaburen neighbourhood. Therefore, meetings to inform the residents and value their opinions should be organized through the MFC. In addition, the presence of a website makes the communication among inhabitants and institutions effective even without attending such meetings, as information, surveys and updates can be posted online. Therefore, social inclusion and participation in the decision-making processes can be guaranteed by creating a partnership with local foundations, like the MFC.

- **Local social acceptance**.

To evaluate the social acceptance of Camminghaburen toward a floating PV system installed in their neighbourhood a survey is proposed to the resident. The two Facebook groups are used as communication means to send the survey online. The survey starts with an investigation of the general knowledge and perspective of the inhabitants towards solar energy. Next, statements related to different types of PV systems, including floating PVs, are proposed to examine what the resident would prefer and accept. Finally, a digital model of the floating PV system is proposed to provide an overview of the installation and its location, and the residents have to express their opinion on it by indicating the level of agreement with some statements. On a period of 45 days, a total of 32 responses were registered. The content of the survey and the answers are reported and analysed in the figures below.

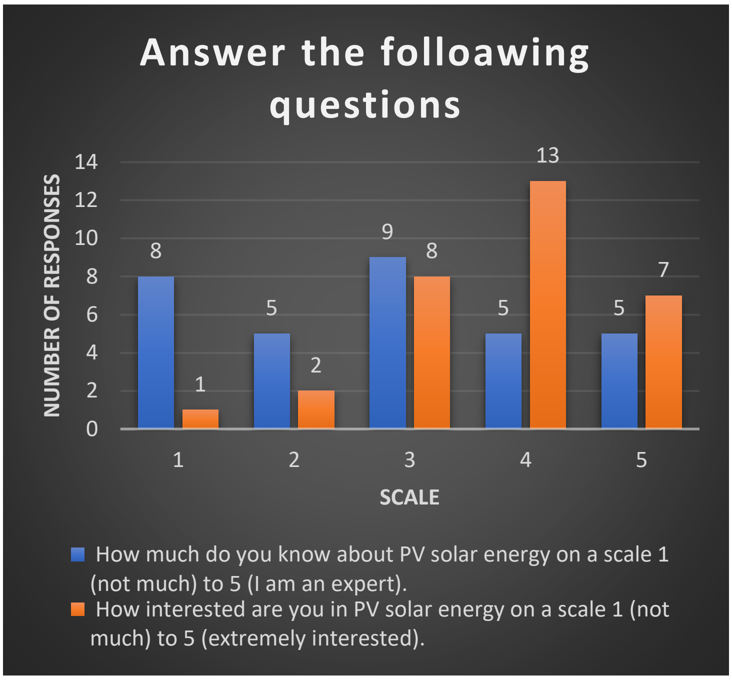

Figure 25: Histogram showing the level of awareness of the residents towards PV solar energy.

These two general questions are used to get a general understanding of the level of knowledge and interest in solar energy. From the responses, it is clear that most of the residents are both interested and aware of solar PV energy. Thirteen answers indicate a level of interest of four. In addition, seven respondents indicated to be experts in the field and five to be extremely interested. Only one person is not interested in the topic, and eight do not know much about PV power generation. However, on average, the results show awareness and interest from the residents.

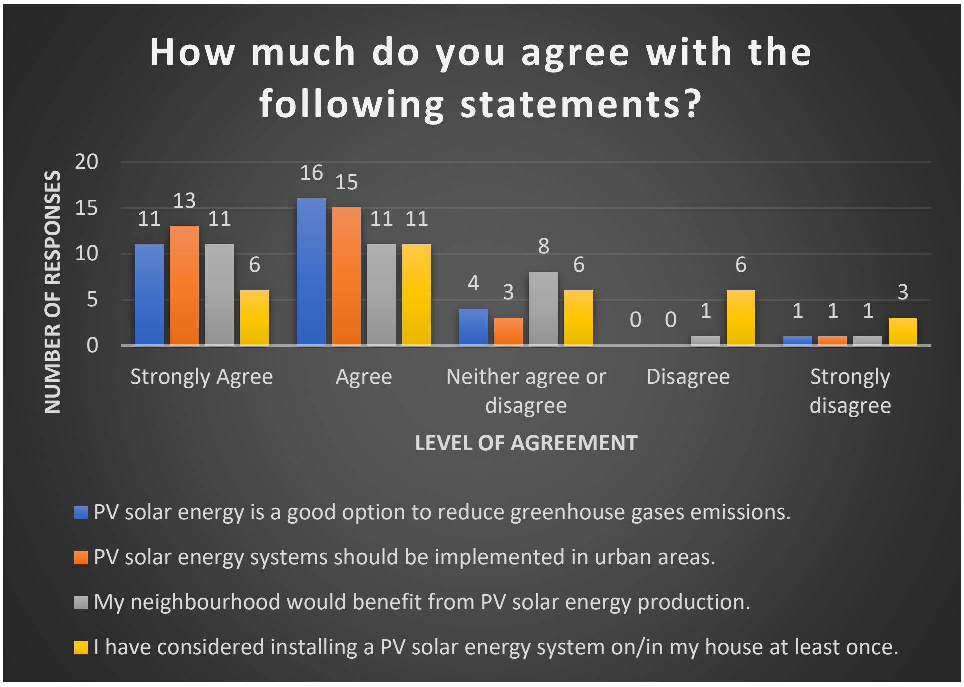

Figure 26: Histogram showing the level of knowledge and opinion of the residents towards PV solar energy.

These statements further investigate the inhabitants' knowledge and opinion of solar PV energy. The responses indicate that most of the residents consider PV solar to be a good option to reduce greenhouse gases emissions and that they should be implemented in urban areas. In addition, 22 respondents out of 32 think that the Camminghaburen neighbourhood would benefit from PV solar energy production and 17 have considered installing PV panels for his/her house at least once. Finally, most of the residents are aware that PV energy can help to reduce electricity bills. Again, these responses indicate good knowledge and awareness from the inhabitants.

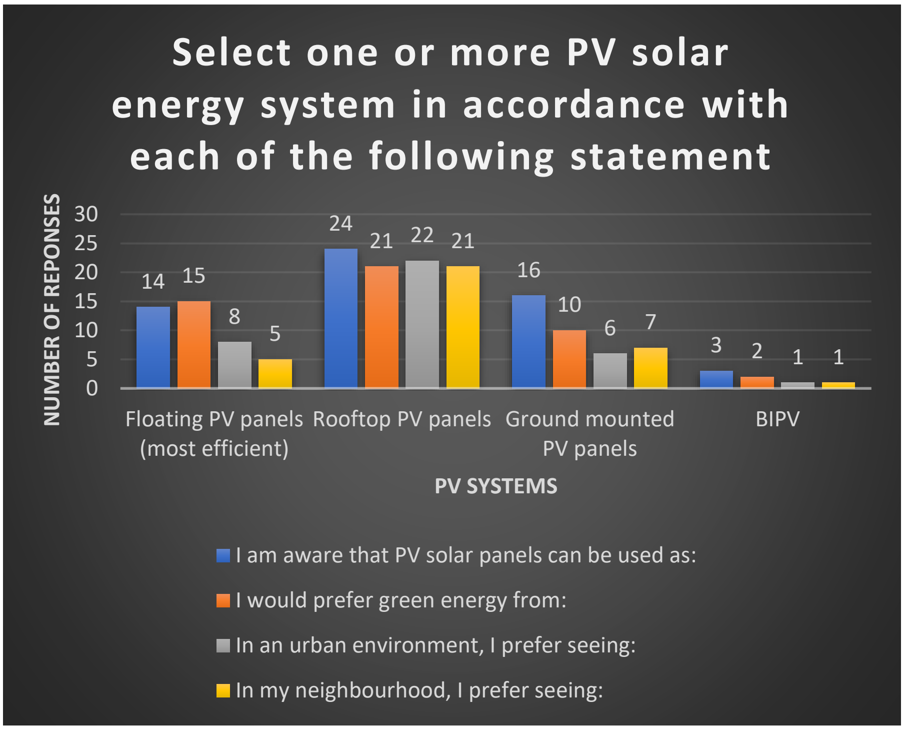

Figure 27: Histogram showing the residents' opinion towards SETs.

These statements are used to investigate what residents know and think of different PV solar applications. The responses indicate that 14 of the inhabitants are aware of the existence of floating PVs. However, the most recognized modules are the rooftop and ground-mounted ones. Interestingly, only 3 people know about Building Integrate PVs (BIPVs). BIPVs are the type of application that received the smaller number of responses. On the other hand, rooftop solar is by far the preferred option by the residents of Camminghaburen. In fact, it received the highest number of responses for each statement. Besides, some inhabitants showed interest in floating solar. 15 people would prefer green energy from floating solar, probably because is the most efficient one. 13 respondents indicated that they would be interested to see a floating PV plant in an urban environment (8) or their neighbourhood (5). These results are similar to those of the ground-mounted PVs. From these statements, it is possible to start having an idea about the general opinion of the respondents towards floating PVs. For now, it is reasonable to say that the inhabitants could accept this type of solar installation in Camminghaburen, but further investigation is necessary.

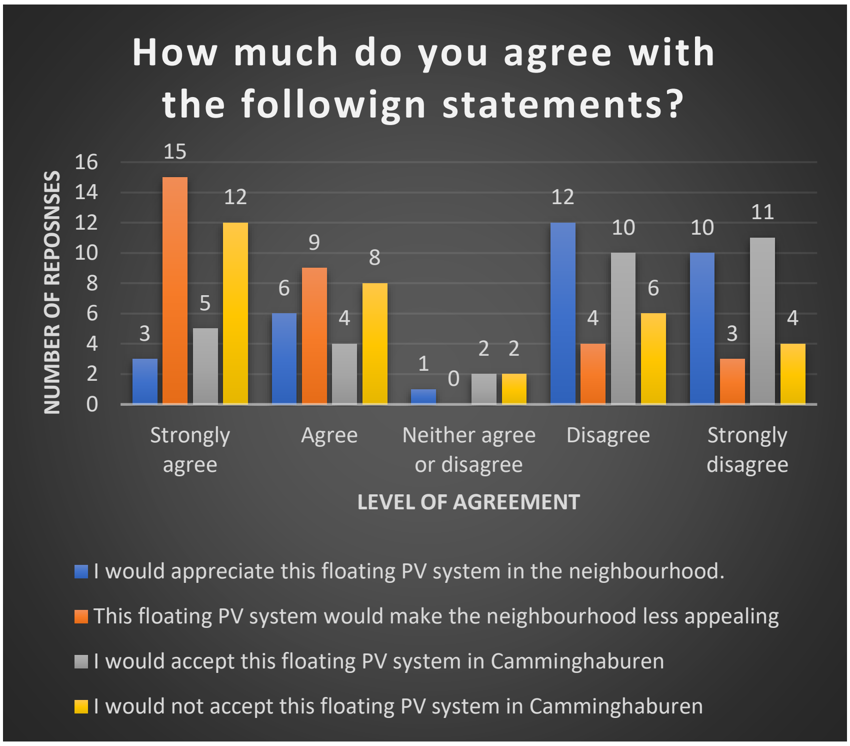

Figure 28: Histogram showing the residents' opinion towards a floating PV system in Camminghaburen.

These are the last statements proposed and are used to investigate the residents' acceptance of the floating PV designed in Camminghaburen. The responses indicate that most of the inhabitants would not appreciate such a system in their neighbourhood. As a matter of fact, 22 answers affirm that they either disagree or strongly disagree with the statement represented in blue. In addition, the majority of the respondents indicated that they would be concerned about the visual impact that the floating PV system would have on the area. As a matter of fact, 24 of them agreed on the fact that this solar plant would make the neighbourhood less appealing. Only 7 respondents disagreed with such a statement. This result is also found when analysing the answers to the last two statements. In fact, 21 respondents would not accept the floating system in Camminghaburen, while only 9 would accept its implementation.

The results of the survey show that, on average, Camminghaburen residents are aware of the possible benefits of solar energy. Besides, most of the inhabitants showed interest in the installation of PV panels for their houses and neighbourhood. In addition, it is clear that the preferred application for solar modules is rooftop PVs. The responses also showed that ground and floating panels are perceived similarly, suggesting that floating could take the place of land systems in the built environment. Nevertheless, when analysing the statements that concern the acceptance of the floating PV system on the canal in Camminghaburen, it is clear that the residents would not welcome such a power plant in their neighbourhood. This reaction can be related to the "Not in my backyard" phenomenon, according to which the development of an energy system in a district is perceived as inappropriate by the inhabitants. This finding must be properly valued during the decision-making process and can be a major barrier to the construction of the floating PV system in Camminghaburen.

- **Local leisure activities interferences**.

This indicator is evaluated by carrying out an on-site empirical analysis. From such an investigation it is found that the construction stage would interfere with the fishing activities that the canal supports. As a matter of fact, it is not uncommon to see people fishing in the canal from Kronenberger Park. The installation activities would probably disrupt the possibility of fishing on the site, but only for the construction period. However, once the system is installed, people can easily start fishing again, meaning that this activity would only be temporarily disrupted. In addition, the survey happened to be helpful to further analyse this indicator. In fact, in the section for suggestions, the respondents wrote some relevant statements that describe how other local leisure activities could be disrupted by the construction of the floating PV system. One respondent affirmed: “The Kronenberger Park has just been renovated to make recreation, etc., and the neighbourhood more attractive. And in winter people skate here, in summer children swim, etc… So don't do it!”. These statements clearly highlight that the construction of the floating PV system would interfere with seasonal leisure activities, like ice skating during winter and swimming in summer. On the other hand, another resident wrote a positive statement regarding the implementation of such a system in the district: “Do it, it might become a tourist attraction and a case example to investigate floating PVs installation in cities”. Therefore, this solar plant could create new socio-economic activities that would benefit the area. Nevertheless, considering the responses of the survey, this is an isolated opinion. Therefore, it is reasonable to say that the floating system would interfere with the local leisure activities.

- **Noise pollution**.

This indicator is evaluated by doing a literature review of journal papers. In general, noise pollution during the construction phase causes potential hazardous to the workers and the residents. According to the European Centres for Disease Prevention and Control, after 2 h of exposure to 80–85 decibel noises, the hearing ability can be damaged. Therefore, the construction stage of a PV project must comply with noise control regulations and continuously monitor the noise level. Since these disturbances occur on land, noise barriers can be used to mitigate them during construction works. The use of noise barriers should solve the issue of on-land noise pollution. In addition, to protect the workers, soundproof headphones should be provided to them (Tawalbeh, et al., 2021). This is the last indicator related to the construction stage, meaning that the evaluation of the operation & decommission activities can start.

4.3 OPERATION & DECOMISSION

The operation & decommission start with the identification of the sustainability indicators related to the activities that are carried out during this stage. The technical, economic, environmental, and social indicators during operation & decommission are identified from journal papers and reports reviews. The main objective of their evaluation is to generate results that illustrate whether operation & decommission activities can be carried out sustainably. Different analysis methods are used to generate valuable data and information from the indicators identified. Just like for the construction, this stage of the energy project development concerns the implementation of the third and fourth steps of the decision-support framework.

4.3.1 IDENTIFICATION OF INDICATORS

The indicators identified from literature and reports necessary to assess the sustainability of the operation & decommission activities are categorized by the four pillars of the framework.

4.3.1.1 Technical indicators

The identification of the technical indicators for this stage is based on considering the energy-related issues during operation. In addition, the technicalities of the decommissioning activities are important factors to consider for their identification. These indicators are:

- **Yearly energy consumption per household**, which must be known to evaluate the potential energy contribution of the floating system (Extebarria, 2018).
- **Produced energy**, to measure the yearly generation and evaluate the potential energy contribution of the floating system (Durkovic & Durisic, 2017).
- **Energy contribution to the location**, to analyse how much energy demand the floating PV system can cover per year (Evans, Strezov, & Evans, 2009).
- **Losses during operation**, which refer to analysing the possible factors that can lead to energy performance losses (Apribowo, Suyitno, Santoso, & Wicaksono, 2019).
- **The lifetime of the floating PV system** (Afgan, Carvalho, & Hovanov, 2000).
- **Security and diversity of supply**, which concerns analysing the monthly energy production to understand when the availability of energy from the floating PV plant is low (Durkovic & Durisic, 2017).
- **Decommission**, which refers to the technical management of the decommissioning activities (Silva & Branco, 2018).

4.3.1.2 Economic indicators

The economic indicators are related to the financial management of the operation & decommission activities. Therefore, the following economic aspects and impacts are identified:

- **Cost of electricity**, consisting of measuring the LCOE of the floating PV system (Fiksel, Eason, & Frederickson, 2012).
- **Electricity sale**, which refers to estimating the feed-in tariff of the energy system (Durkovic & Durisic, 2017).

- **Payback time**, which consists of estimating the time needed for the total investments to be paid off (Fiksel, Eason, & Frederickson, 2012).
- **Return of investments**, which refers to analysing the feed-in tariff gains after the energy system is paid off (Fiksel, Eason, & Frederickson, 2012).
- **Decommission costs** (Silva & Branco, 2018).

4.3.1.3 Environmental indicators

The environmental indicators are related to the environmental aspects and impacts of the floating PV system operation & decommission works. The following indicators are identified for this dimension of sustainability:

- **Water and air pollution**, which refers to analysing any possible source of habitat pollution (Silva & Branco, 2018).
- **Replaced CO_2 emissions**, to estimate the emissions saved throughout the lifetime of the system (Tawalbeh, et al., 2021).
- **Effects on the ecosystem**, which refers to any activity that may improve/disrupt the aquatic, aerial, and terrestrial ecosystems during operation (Ziar, et al., 2020).
- **Environmental impacts of decommissioning activities,** to understand what risks the decommissioning of the system can bring to the surrounding natural habitat (Silva & Branco, 2018).

4.3.1.4 Social indicators

Finally, the social indicators related to social aspects and impacts of the operation & decommission activities are identified. These are:

- **Local leisure activities interferences**, to evaluate whether any leisure and social activities are disrupted by the floating PV system (Afgan, Carvalho, & Hovanov, 2000).

4.3.2 EVALUATION OF INDICATORS

The evaluation of the sustainability indicators identified consists of using different measurement and processing methods to generate the data and information necessary for the assessment of the cooperation & decommission activities. Again, each indicator is categorized by the four dimensions of the decision-support framework and individually analysed.

4.3.2.1 Technical indicators

To analyse the technical indicators related to the operation & decommission works, reports, and journal papers are reviewed and the software PVsyst is used.

- **Yearly energy consumption per household**.

This indicator is analysed using an online database offered by the International Energy Agency that reports the average energy consumption per household in Dutch residential neighbourhoods. The result of the research is that the typical Dutch household consumes 3000kWh/year or 250kWh/month (Ryan & Trudgeon, 2015). This indicator is important to evaluate the potential energy contribution of the floating system.

- **Produced energy**.

The energy generation is automatically measured by PVsyst 7.2 by considering the number of panels, their nominal power, and the weather data of the location, which are downloaded in the software from an online database offered by the Groningen-Eelde Airport. In addition, PVsyst 7.2 allows entering qualitative data that describe the physical characteristics of the installation site, i.e., ground material, percentage of shading covers. Therefore, it is indicated that the bifacial PV modules are positioned on water and that shading is negligible. Finally, the orientation (south) and tilt (37°) of the system are specified. This data permits the software to measure the realistic and optimal electricity generation of the floating PV system installed in Camminghaburen. The result of this analysis is a power production of 111,7 MWh/year, or 9,25 MWh/month.

- **Energy contribution to the location**.

To measure how much energy demand the floating PV system can cover per year the results of the previous indicators are considered. It is known that the floating solar plant produces 111,7 MWh/year and that each household consumes 3000 kWh/year (3MWh/year). This is equal to consume 1000 m^3 of natural gas per year (Dodman, 2009). Therefore, by dividing 111,7 MWh/year by 3MWh/year, it is possible to estimate the exact energy contribution in terms of the number of families whose energy demand is covered by the solar system. The result is 37 families. As a result, the floating PV system can feed in the grid the amount of energy used by 37 households of Camminghaburen in one year.

- **Energy security and supply**.

To estimate the energy security and supply of the floating PV plant PVsyst is used. Using meteorological data, downloaded in the software from an online database, and the energy produced per year. The results are shown in the figure below.

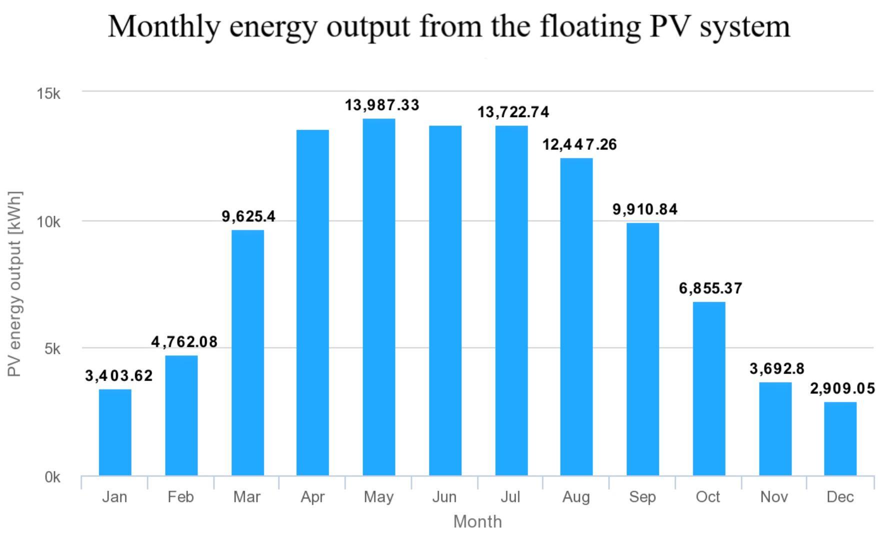

Figure 29: PV energy output of the floating system VS months.

Considering that the floating system must provide electricity for 37 families throughout the year and that each family consumes 3000 kWh/year, or 250 kWh/month, the floating PV system should generate at least 9250 kWh/month to sustain the energy consumption of all the 37 households each month. By visualizing the results, it is clear that the months with the lowest energy production happen during winter and fall. As a matter of fact, in January, February, November, and December, the energy output reaches a maximum of 4762 kWh/month. During March and October, the maximal output is 9625 kWh/month and 6855 kWh/month, respectively. Therefore, during these months the floating plant is not always able to generate enough electricity to meet the energy demand of all the families. As a result, a backup energy source should be used. In the case of Camminghaburen, natural gas should be used as an alternative source of power when solar energy is lacking. On the other hand, during the rest of the months, namely from April to September, the floating PV panels generate enough power to sustain all 37 families. Therefore, no backup energy source is required, as energy security and supply are guaranteed.

- **Losses during operation**.

To evaluate this indicator reports are reviewed to collect information related to the factors that could lower the energy performance of the system during operation. Reports from Ciel & Terre affirmed that the main factor that leads to energy losses of floating PV systems is birds' faeces. As a matter of fact, water bodies attract many species of birds, regardless of the location of the plant. Leeuwarden is a city close to the coast, and there are seagulls, pigeons, ducks, and several other species of birds that rely on the canals to feed and rest (Terre, 2017). Therefore, their interaction with the floating panels is almost inevitable. In addition, strong winds, which in winter are frequent in Leeuwarden, waves, and cold weather can change the orientation or the position of the system, leading to energy losses and possible damages to the floating components. To mitigate these issues, maintenance activities are important (Terre, 2017).

- **Maintenance activities**.

Being in a dynamic environment, the floating PV system must be periodically maintained and monitored. According to the reports from the company Ciel & Terre, the conditions of the pontoons, the mooring, and the anchoring system must be checked once a year, ideally after every winter, when harsher climates are expected. This is done to make sure that the position and orientation of the panels did not change and that the metallic elements are not corroded or damaged. On the other hand, the conditions of the PV modules must be constantly monitored. Cleaning the surface of the panel is the main maintenance activity and must be carried out on a monthly basis. However, periodical monitoring is necessary to empirically analyse the issue and determine whether more frequent cleaning is necessary. In addition, monthly checks are done to make sure that the panels did not suffer any damage and are not realising substances in the natural habitat (Terre, 2017).

- **The lifetime of the floating PV system**.

The lifetime of the floating PV system is measured on the base of the components selected. Therefore, the data are retrieved from the manufacturing companies' websites. According to GCL System Integration, the bifacial PV modules selected have a guaranteed lifetime of 25 years (GCL, 2011). The HDPE pipes produced by BIS Floats can be operational for over 50 years (Floats, 2016). Finally, the mooring system and the anchors have a guaranteed lifespan of more than 100 years (SEAFlex, 2015). As a result, the lifetime of the system is 25 years, as it is predominantly limited by the short lifespan of PV modules. However, the other components can be reused either to mount new solar panels on the same site or to develop a new floating PV project in a new site. For this floating PV system, it is estimated the total lifetime of the system to be 25 years. After that period the decommission of the components should start.

- **Decommission**.

A literature review shows that the decommission of the energy system starts when the PV modules reach the end of their lifetime. In fact, PV solar panels are the first components of the power plant to become waste. After 25 years the panels can be either recycled or sent to landfills. Ideally, the bifacial panels used for this solar system are recycled, but this decision is strictly economic. Similarly, after 50 years the pontoons must be decommissioned. However, it should be easier to either recycle or reuse these elements, as their second-hand market is vast. Finally, the decommissioning of the mooring and anchoring system must be carried out. Although their life span is more than 100 years, it is suggested to decommission these elements together with the pontoons. Specialized personnel is needed to carry out these activities in a way that the effects on the natural habitat are minimized (Acharya & Devraj, 2019).

4.3.2.2 Economic indicators

To evaluate the economic indicators related to the operation & decommission works, reports, and journal papers are reviewed and the software PVsyst is used.

- **Cost of electricity**.

The cost of the electricity produced by the floating PV system is automatically measured by PVsyst 7.2. As a matter of fact, by considering the capital costs of the construction, the expanses during operation & decommission, and the energy produced, the software estimates the LCOE of the power plant. The result is an LCOE of 0,057 €/kWh, which approximated to real-life tariffs is 0,06 €/kWh.

- **Electricity sale**.

The sale of electricity is measured by PVsyst 7.2. As a matter of fact, the software uses an online database to estimate the feed-in tariff of the floating PV system. The feed-in tariff is a policy that allows investors to gain profit by selling to the national grid the surplus electricity produced by the power plant. For solar energy, a reasonable feed-in tariff is 0,17 €/kWh during peak periods of electricity consumption. For off-peak periods, the tariff is 0,10 €/kWh.

- **Payback time**.

The payback time of the installation is measured with PVsyst 7.2. The average feed-in tariff is thus calculated for the lifetime of the floating PV panels (25 years), to evaluate the payback time of the installation. The result is a payback time of 4,7 years. Considering that, in 2020, the average payback time of solar installations was 8 years. This result indicates that optimal economic performance is achieved during the operation of the energy system. After the payback time, the feed-in tariff becomes a profit.

- **Return on investments**.

This indicator is automatically measured with PVsyst. To do it, the software uses the average feed-in tariff and the lifetime remaining after the payback time is reached. Therefore, the results show the net value of the floating PV system, the return on investments in %, and the distribution of the profit to pay the operation and decommission expenses, namely the paid dividends (Table 7). In other words, the paid dividends correspond to the operation and maintenance costs and are equal to 30% of the net value of the installation. They must be added to the capital costs to know the total expanses of the installation.

Net value	516576,70 €
Return on investment	317,5%
Paid dividends	95670 €

Table 7: Results of the return of investments analysis of the floating PV system.

- **Decommission costs**.

Decommission activities generate costs mainly related to dismantling the system and waste management. A review of the literature shows that the cost of dismantling solar plants is approximately 15% of its net value (Ziar, et al., 2020). Therefore, it is estimated that 32486.50 € is necessary to break up the floating PV system. After this phase, the components of the plant inevitably become waste, which must be managed in a way that expanses are maintained low and negative effects on the environment minimized. According to a report of the National Renewable Energy Laboratory, it currently costs 16€ to 25€ to recycle a panel and only 1€ to 2€ to send it to the landfills. Materials like glass, silver, and aluminium framing should thus be recovered. In addition, the inverter can be taken apart and internal components sold in the market to be recycled. The expensive material to recycle is the crystalline structure and lead. In fact, once it reaches the end of its lifetime, panels produce a highly toxic compound, namely, silicon tetrachloride (Acharya & Devraj, 2019). However, such substances can be separated, and silicon can be recycled to create new PV polycrystalline cells. As a result, it is estimated that the waste management of this system costs 18€ per panel, meaning that the total expenses are 8640€. As an alternative, to maintain low costs, the panels can be sent to landfills, and the expenses would amount only to no more than 880€, but the environment would be harmed. For this energy project, it is suggested to recycle the materials of the components as much as possible to minimize negative environmental effects.

4.3.2.3 Environmental indicators.

The environmental indicators related to the operation & decommission of the floating PV system are analysed and measured using PVsyst and literature and reports review.

- **Water and air pollution**.

Literature is reviewed to analyse the possible sources of environmental pollution during operation. Throughout time corrosion of metals is expected. Therefore, elements like the aluminium framing and the bolts used to connect the anchors with the mooring system are expected to be a source of water contamination due to corrosion. Similarly, PV modules contain lead, and damages to the cells can cause leakages of such a substance in the water. Monitoring and possibly substituting metal elements and PV panels is important to mitigate these issues. Furthermore, air pollution is expected to be generated using vehicles to access the site. As a matter of fact, boats must be used to carry out maintenance and monitoring activities, meaning that CO_2 is emitted into the atmosphere. Reporting the amount of time and fuel necessary to carry out these activities is important to quantify the impact of this aspect. Since no land is used for this PV system, aspects related to soil pollution are negligible. However, being a novel type of solar application, the environmental pollution of floating PV systems is still under examination, and long-term effects are unknown. Therefore, besides this analysis, it is difficult to further illustrate any other source of pollution related to floating PVs operation (Extebarria, 2018).

- **Replaced CO_2 emissions**.

According to a literature review, households in the Netherlands produce on average 3,2 tons of CO_2 emissions per year (SOURCE). To measure the amount of replaced CO_2 emissions during operation PVsyst is used. The software considers the amount of green energy produced, namely 111,7 MWh/year and the CO_2 emitted during construction, 229,3 tons of CO_2, to automatically estimate the saved CO_2 emissions over the lifetime of the floating PV plant. The result shows that an outstanding amount of 708,8 tons of CO_2 emissions are saved throughout the 25 lifetime years of the panels. In figure 29 the result is shown in a graph of the saved CO_2 emissions VS time.

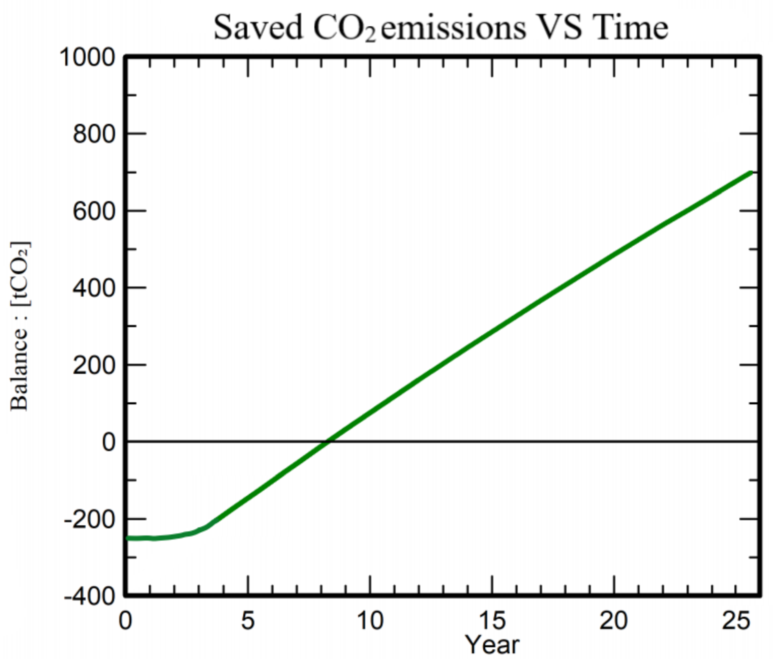

Figure 30: Saved CO_2 emissions over the 25 lifetime years of the floating PV system. The line represents the amount of CO2 replaced per year. It starts negative, as during the construction stage emissions are generated from manufacturing components. After approximately 8 years the installation becomes carbon neutral, as the emissions saved are equal to those previously generated. This means that from the ninth year, the floating PV system becomes carbon positive, as the saved emissions offset those previously made.

- **Effects on the ecosystem**.

When applied above water, solar panels can either benefit or damage the aquatic ecosystem of a community. In fact, the shading they create can have both positive and negative effects on the canal, depending on its biological characteristics. Levels of oxygen and index/rate of algae growth are essential sub-indicators to analyse the actual effects of a floating PV system on the aquatic ecosystem. To measure these factors specialized equipment is necessary and speculation should be avoided (Shau, Yadav, & Sudhakar, 2016). Therefore, for this research project, it was not possible to analyse the sub-indicators, meaning that the potential effects on the aquatic ecosystem of the Camminghaburen canal remain unknown. However, in a real-life project, collecting such information must be done. Constant monitoring of the effects that shading patterns cause on the biological characteristics of the water, i.e., monitoring the level of oxygens and algae growth index during operation, is essential to analyse this indicator (Extebarria, 2018).

- **Decommission environmental impacts**.

The decommission activities also have effects on the environment and they can be analysed using a literature review. When PV panels reach the end of their lifetime, they can be either sent to landfills or recycled. As mentioned, it is suggested to recycle the solar modules after 25 years to minimize their negative impact on the environment. However, in the case the energy project managers must keep decommissioning costs as low as possible, PV panels can also be sent to landfills. When this happens negative impacts on the natural habitat are inevitable as toxic substances, like lead and decayed silicon, are realised and absorbed by the soil. This can harm not only the biodiversity of the surrounding environment but also the communities that live in proximity of these landfills, as aquifers can be contaminated. As a result, the impacts on the ecosystem of the decommissioning activities are strictly related to the decision taken for managing waste (Isabella & Ziar, 2018).

4.3.2.4 Social indicators

To evaluate the social indicators related to the operation & decommission works, reports, and journal papers are reviewed, online research on the neighbourhood's official website is done and a survey is proposed to the inhabitants.

- **Social activities interferences**.

The interferences with social and leisure activities during the operation last throughout the lifetime of the system. Activities like fishing can be affected, as aquatic fauna may find the section of the canal where the floating PV system is installed less attractive. In addition, seasonal leisure activities like ice skating on the canal will be disrupted, as the panels would occupy most of the space available, and it would not be safe for people nor the system itself to have residents playing around it. In addition, it is not certain to what extent the installation would decrease the availability of the canal for boats and leisure activities like canoeing and paddling. However, for this research project, it is suggested that the passage of boats is not affected, as the arrays are strategically positioned in a way that a lot of space remains available. Similarly, if safe distances are maintained, canoeing and paddling can still happen in that section of the canal. To make sure that these leisure activities are not affected, a floating delimitation, composed of ropes and buoys, that surround the PV system should be applied. In this way, health and safety during operation can increase. This is the last indicator to be evaluated for the operation & decommission stage, meaning that the assessment can begin.

4.4 ASSESSMENT OF INDICATORS

The findings of the evaluation are now juxtaposed to the goals sought to be achieved to carry out the last step of the framework, namely the assessment of indicators. Therefore, the sustainability assessment of this research project can be concluded to understand whether the floating PV system can promote sustainable energy development in the neighbourhood considered and thus in an urban context.

4.4.1 SDG 7: AFFORDABLE AND CLEAN ENERGY

Each goal is related to the corresponding findings of the evaluation.

- The energy and economic performance of the floating PV system must be optimized.

The energy performance of the floating PV system is optimized through the analysis of some technical indicators belonging to the construction and operation & decommission stages. As a matter of fact, shading patterns are investigated by developing a digital 3-D model with SketchUp (Figure 20). This analysis allowed to create an optimal scenario for the floating PV plant, where incident sunlight is not hindered by the shading of the surrounding elements and the modules throughout the day. Consequently, the ideal design of the system and the surroundings is proposed in a final 3-D model. The ideal position of the arrays to ensure optimal absorption of light is thus shown in Figure 21. Next, the realistic size of the floating solar installation is illustrated to specify the number of arrays (20). In addition, the number of units per component i.e., the pontoons (10), mooring (10) system, and anchors (40), necessary to stabilize the orientation and position of the PV panels are described. These elements permit the system to maintain optimal performance throughout time. Subsequently, to quantify the energy performance, the nominal power of the floating PV plant designed is calculated to be 110 kWp. Furthermore, the produced energy by the installation is estimated to be 111,7 MWh/year, or 9,25 MWh/month, meaning that the system has a large potential in terms of energy contribution to the neighbourhood, as the average energy demand of a household is 3000 kWh/year. Finally, the possible losses during operation are considered, and activities to mitigate and erase them are described. To do it, the main suggestion is to periodically carry out monitoring and maintenance activities, especially when it comes to clean the panels from birds' faeces and checking the conditions of the system after harsh weather. These analysis actions permit engineers to make sure that the floating PV system can achieve an optimal energy performance within the spatial and time boundaries considered.

The economic performance is optimized through the analysis of some economic indicators belonging to the construction and operation & decommission stages. The capital costs of the installation are estimated to be 66983.00 €. However, 30% of these costs are covered by governmental subsidies. To these, 95679.00 € are added during operation and maintenance for the paid dividends. As a result, the total capital costs necessary to install and operate the floating solar system are 162662.00 €.

Considering that the system has a net value of 516576,70 € throughout its lifetime, the return of investment is equal to 317,5%. This means that 353914.00 € is the actual profit that the floating plant would be able to produce for 25 years. In addition, the payback time is estimated to be only 4,7 years, which is well below the average period of 8 years (B.Parida, S.Iniyan, & R.Goic, 2011). This indicates that not only the system will be able to be paid back sooner than expected, but it will also start creating profit as soon as that point is reached. Finally, the LCOE is estimated to be 0,06 €/kWh, which is exactly the average cost of solar electricity in 2021 (B.Parida, S.Iniyan, & R.Goic, 2011). As a result, it is reasonable to say that by carrying out the analysis of these indicators, the economic performance of the floating PV system can be optimized. In conclusion, this assessment suggests that this goal can be achieved.

- The floating PV system must generate clean energy for the households of Camminghaburen.

The cleanness of the energy generated from the floating PV plant is evaluated by considering some of the environmental factors related to the construction and operation & decommission stages. Therefore, the sources of air and water pollution caused by the system are taken into account to assess the possibility of achieving this goal. From the analysis of the environmental indicators, it is found that, although specialized encapsulations and materials make the components of the plant water-resistant, some levels of corrosion are expected to happen from the aluminium framings and bolts. In addition, the panels, that are constantly exposed to dynamic and wet conditions, can suffer damages leading to leakages of toxic substances like lead. These are the potential sources of water contamination and pollution from the floating system. Although they can be mitigated through monitoring and maintenance, it is expected that at a certain point of the system's lifetime such issues will occur and will inevitably influence the aquatic ecosystem. However, it is important to mention that long-term water pollution problems are not completely understood yet. In fact, floating PV technology is a novel application and further monitoring of systems is necessary to gather reliable data and information that properly define this issue.

Besides, activities related to site accessing and the use of machinery to move and assemble components are expected to be a source of air pollution. As a matter of fact, fossil fuel is needed to power vehicles and machinery, leading to inevitable CO_2 emissions in the atmosphere. Furthermore, air pollution is expected during the construction stage. In fact, manufacturing the floating PV components causes an amount of CO_2 emissions equal to 229,32 tons. Nevertheless, these air pollution issues become negligible when the saved CO_2 emissions are estimated. Indeed, considering the amount of energy generated i.e., 111,7 MWh/year, the replaced CO_2 emissions are equal to 708,8 tons, offsetting the emitted CO_2 by almost 480 tons. As a result, it is reasonable to say that the air pollution issue does not represent a barrier to generating clean energy. On the other hand, corrosion and leakages are inevitable sources of water contamination and pollution. This represents a possible barrier to the production of clean energy for the neighbourhood, meaning that this goal cannot be fully met even if the system is carbon positive.

- The floating PV system must generate affordable energy for the households of Camminghaburen.

The affordability of the generated energy is assessed by considering one economic indicator related to the operation & decommission stage. This indicator is the cost of electricity or the evaluation of the LCOE of the floating PV system. The result is an LCOE equal to 0,06 €/kWh, which is exactly the expected price of electricity produced by solar energy systems in 2021 (B.Parida, S.Iniyan, & R.Goic, 2011). Considering that the economic condition of Camminghaburen meets the national average, it is reasonable to say that the floating PV system can produce affordable energy for the households of the neighbourhood.

- The floating PV system must contribute to diversifying the energy mix of Camminghaburen.

The possibility of achieving this goal is assessed using the analysis of technical indicators related to the operation & decommission stage. The energy consumption in Camminghaburen is equal to 3 MWh/year and is currently supported by a natural gas power plant. In fact, 1000m^3 gas/year is consumed by the households of the neighbourhood. Considering that the floating PV system can produce 111,7 MWh/year, it is estimated that it can prevent 37 households of Camminghaburen from using natural gas. This means that 9250 kWh/month is necessary to meet the power demand of those 37 households. However, the energy produced from the floating PVs is not the same throughout the year. In fact, during the winter months, the panels are not able to generate enough electricity to sustain all 37 families. This means that the system designed can contribute to diversifying the energy mix of the district but must be supported by natural gas energy when it cannot generate enough electricity. As a result, it is reasonable to affirm that the floating PV system can contribute to meet this final goal related to SDG 7.

4.4.2 SDG 11: SUSTAINABLE CITIES AND COMMUNITIES

- The development of the floating PV system must be characterized by the participation and inclusion of Camminghaburen residents in the decision-making processes.

The assessment of this goal is based on the results of two social indicators related to the construction and operation & decommission stages. The analysis of the social participation suggests that creating a partnership with the local MFC centrum can guarantee communication between the residents, the representatives of the neighbourhood, and the managers of the energy project. In addition, the presence of an official Camminghaburen website can strengthen communication among inhabitants and institutions. Therefore, communication means are in place to ensure that the local community is involved during the decision-making processes. As a result, it is reasonable to say that social participation during the development stages of the energy project can be guaranteed. This goal is especially important to create a communication mean through which it is possible to investigate the social and economic acceptance of the floating system in Camminghaburen. These are essential indicators to be evaluated in order to understand whether the installation of the power plant would be welcomed by the inhabitants of the area.

- The floating PV system must be socially accepted by the residents of Camminghaburen.

To assess the local social acceptance toward the installation of the floating PV system in Camminghaburen the answers of the survey are used. In general, the respondents showed awareness and interest in solar energy and its applications. As a matter of fact, they think that PV panels should be implemented in urban areas as they can reduce CO_2 emissions and that their neighbourhood would benefit from them. 17 out of 32 participants answered that they considered installing PVs in their house at least once. These replies indicate that, potentially, there are the right social conditions for solar energy to thrive in Camminghaburen. In addition, the respondents showed that the preferred solar application is rooftop systems. Nevertheless, floating PVs and ground-mounted also received substantial recognition and interest, even though not many people admitted that these two systems would be welcomed in the neighbourhood. This finding is consistent with the responses registered for the analysis of the floating PV system acceptance. In fact, most of the participants showed negative acceptance toward the installation of such a system in their district. This means that residents of Camminghaburen would not accept such a system on their central canal, mainly because they would be concerned about the visual impact and the interferences with seasonal leisure activities. The opinion of the inhabitants is one of the main factors to determine whether the construction activities of the floating PV system in Camminghaburen should take place or not. Therefore, this low social acceptance could represent a major obstacle to the development of the power plant. As a result, this goal is not met.

- The floating PV system must create income and jobs opportunities for the residents and boost the economy of the neighbourhood.

To assess the possibility of achieving this goal, economic and technical indicators are considered. The floating PV system can generate profit after only 4.7 years from its installation. Furthermore, the presence of feed-in tariffs guarantees that the system will generate profit once it is paid back. Nevertheless, the possibility of benefitting the residents and the local economy is strictly related to the financing plans of the power plant. In fact, the floating PV system is economically beneficial for the inhabitants of Camminghaburen only if they decided to pay for the installation of the system. Such a payment would consist of dividing the total costs by 37 households, considering that subsidies are expected to cover 30% of the expenses. Therefore, 37 inhabitants should pay 112045 €, or 3028,24 € each, to contribute to the installation costs and economically benefit from the system once it is paid back. On the other hand, in the case private and public companies invest in the system, it would not be as beneficial for the local community, as only those companies will economically profit from it. As a result, to properly assess this goal, the results of the survey that investigated the local economic acceptance of solar energy and the floating PV system must be considered. The results show that most of the residents are aware that solar PVs can reduce their electricity bills. Yet, they are not willing to pay for the installation costs of the floating PV system but prefer the public or private sector to invest in the construction of the power plant. This means that the inhabitants of Camminghaburen would not gain any direct economic profit from it and that the floating PV installation is more likely to boost the economy of large corporations and public institutions rather than of the local area and its residents. However, this unwillingness to pay for the installation costs can be explained by the fact that most of the residents perceive solar technology as too expensive, especially when initial expenses are considered.

Throughout the lifetime of the floating PV system (25 years), several job opportunities are expected to be created. To be precise, it is estimated that around 85 jobs would be generated during the construction and operation & decommission stages. In addition to this, statistics show that for every job created by the PV industry, between 1.8 and 2.8 jobs are expected to be generated in other sectors of the economy. Therefore, the construction, operation and decommission activities of the floating PV system will double the jobs opportunities so that around 170 jobs are created in total. As a result, the floating PV system in Camminghaburen would provide the conditions to generate several job vacancies that could contribute to the economic growth of the neighbourhood, the city, and even the region and the nation. However, such vacancies require specialized personnel, meaning that the Camminghaburen residents should have the technical or managerial educational background to work in such an energy project. Finally, the fact that construction and operation & decommission of the system would not interfere with any local businesses' activities suggests that the floating PVs would not cause any damages to the current socio-economic situation of the neighbourhood.

In conclusion, it is reasonable to affirm that the floating PV system has the potential to benefit the district's economy. Nevertheless, given the unwillingness of the inhabitants to pay for it, this goal is difficult to be achieved on a local scale, but rather it is expected to be beneficial from an urban, regional, and national perspective.

- The floating PV system must not hinder economic or leisure activities that depend on the availability of the canal.

Technical, economic, and social indicators are used to assess the possibility of achieving this goal. The precise position of the floating PV arrays is the first aspect to be considered. As a matter of fact, this analysis was done to make sure that the panels do not hinder the passage of small boats in the canal. The result is 20 arrays positioned in the centre of the canal selected that occupy less than half of the area initially considered, namely 4500 m^2 out of 10000 m^2. Therefore, there is enough space for boats to navigate around the system, meaning that the waterways that intersect in this section would be available for navigation. Besides, no evidence was found related to the possibility of interfering with any local business whose economic profit depends on that section of the canal. Consequently, it is reasonable to say that both the construction and operation & decommission activities would not interfere with any businesses of the district. Nevertheless, the results of evaluating local leisure activities interference showed that the construction of the floating PV system will temporarily (20 days) disrupt fishing activities around the canal. More importantly, the survey helped to collet valuable information indicating that the solar plant would interfere with the seasonal leisure activities of the neighbourhood. As a matter of fact, that section of the canal is used by residents to ice skate during winter and to swim during the warm seasons. The floating system would inevitably disrupt such activities, meaning that this goal cannot be fully met.

- The construction and operation & decommission of the floating PV system must cause minimal negative effects on the surrounding environment, the aquatic ecosystem, and Kronenberger Park.

The possibility of achieving this goal is assessed considering the results of the environmental indicators analysis. The components and machinery used to assemble, operate, and decommission the floating plant are a source of water and air pollution. As a matter of fact, metals and plastics are used for the floating system and the PV panels. These elements are subject to corrosion, which causes unwanted substances to be released into the water. Similarly, damages to PV modules can cause toxic materials, like lead, to enter the water. These negative effects on the aquatic ecosystem of the canal are inevitable but can be minimized by constantly monitoring and maintaining the components of the system. Sources of air pollution are heavy machinery and vehicles necessary to access the site and assemble the components. Commonly these elements are powered by fossil fuels and must be used throughout the lifetime of the system. This means that CO_2 emissions are expected to be generated for the whole 25 years. However, the use of a motorless platform and of electric vehicles to access the site would decrease the impact of these activities on the environment during construction and operation & decommission. In addition, the fact that the floating PV system is carbon positive after approximately 8 years, makes these emissions negligible. As a result, it is reasonable to say that the sources of water and air pollution can be minimized, so that negative environmental effects on the canal and the surrounding area are substantially diminished.

Besides, during construction and operation & decommission activities, Kronenberger Park may be damaged, and its ecosystem disrupted. In fact, negative effects on Kronenberger Park and the aquatic ecosystem may be caused by noise pollution generated from the use of heavy machinery boats, and vehicles. However, it is possible to minimize the negative environmental effects of noise pollution by installing sound barriers around the construction site. Such barriers would also be useful to mitigate social disturbances due to noise pollution. Similarly, it is possible to minimize and avoid any disruption on the land ecosystem, especially on Kronenberger Park, simply by preventing heavy machinery to be used in its proximity. Also, accessing the site from the park should be avoided in order to minimize negative effects on the surrounding area.

Another important aspect to be considered is the decommission impacts on the natural habitat. These can be minimized by sending the components of the floating PV system to recycle factories once the end of their lifetime is reached. In this research project, it is suggested to follow this procedure even if this means increasing the decommissioning costs. As a matter of fact, sending PV panels and the other components to landfills would be cheaper, but would inevitably cause pollution and ecosystem disruption. It is thus reasonable to affirm that this goal can be partially met, as negative effects on the surrounding environment are inevitable, but can be substantially mitigated.

4.4.3 SDG 13: CLIMATE ACTION

- The floating PV system must contribute to reducing the CO_2 emissions within the neighbourhood and the city.

Given that the floating PV system is carbon positive and that it would be able to support the energy consumption of 37 households of the neighbourhood, it is reasonable to say that this goal can be met. As a matter of fact, the average Dutch family generates 3,2 tons of CO_2 emissions in one year. Considering the lifetime of the system, 25 years, it is reasonable to say that the floating PV system avoids 80 tons to be emitted into the atmosphere. In addition to this, the total CO_2 emissions that the PV energy plant can replace is equal to 708,8 tons.

The last step of the decision-support framework is now concluded, meaning that the sustainability assessment of the floating PV system in Camminghaburen has been carried out. Since not all the goals are met, it is reasonable to say that the power plant evaluated should not be implemented in the residential district selected. The results of this assessment are analysed in the next chapter.

5. ANALYSIS OF RESULTS

The analysis of the results aims to answer the third and fourth research sub-questions. It starts by considering the effectiveness of the first two steps of the framework and the methodologies used to perform it. The selection and specification of the location are based on methodologies that enable the evaluation of its technical, physical, political, and socio-economic suitability. The techniques used to carry out this step consists of online research to identify the political, economic, and social characteristics of the area and understand whether the conditions are in place to support the development of SETs. In addition, the technical and physical suitability is analysed by carrying out digital and on-site observations that enable the investigation of the shading patterns of the elements surrounding the canal. Therefore, software like SketchUp Pro and Google Earth are used. These approaches happened to be very helpful to generate a series of qualitative information that enables us to have an overview of the general physical and socio-economic conditions of the neighbourhood. The methodologies used to carry out this step are appropriate and could be applied during the planning stage of a real-life energy project.

The next step of the framework is the definition of goals. The formulation of this step is based on a method used in one of the reports reviewed, according to which the goals must be defined on the basis of the SDGs' principles and the characteristics of the location, and the energy system selected. Again, this methodology happened to be straightforward and effective to define precise goals whose achievement will inevitably promote sustainable energy development in the location considered. As a result, this approach can be applied to define the goals of a real-life floating PV energy project.

Next, the fourth step of the decision-support framework starts. This is the identification of the indicators, and it is carried out on the basis of literature and reports review. As a matter of fact, journal papers and company reports that tackled the assessment of energy systems and floating PV panels using sustainability indicators are read. Therefore, several technical, economic, environmental, and social indicators are collected and identified as relevant for the evaluation of this energy project. Besides, dividing the indicators into those related to the construction stage and those related to the operation & decommission stage helped to make clear when it is important to consider specific aspects and impacts of the energy project.

The evaluation of indicators is the fifth step of the framework, and it is carried out using different methods. These include literature and reports review, the use of SketchUp Pro 2021 and PVsyst 7.2 i.e., a solar energy and economic simulation software, on-site observations, the use of Google Earth, and a survey. Each of these evaluation methods is used to assess one or more sustainability indicators. The methodologies proposed allowed to generate that require the use of software and digital and on-site observations are the most reliable and precise ones. As a matter of fact, they allow engineers to measure quantitative indicators and analyse qualitative ones by generating reliable and realistic data and information that are specific to the location and energy system considered.

Finally, the last step of the framework, namely the assessment of indicators, is considered and discussed. The assessment of indicators is carried out by juxtaposing the findings of the analysis with the goals sought to be achieved. This assessment method is an effective and practical approach to evaluate whether the construction and operation & decommission activities related to the floating PV system implementation can achieve the goals defined and promote sustainable energy development in the neighbourhood. In fact, valuable and clear conclusions can be drawn from such an assessment.

The decision-support framework developed has been effectively applied to a fictional energy project to assess the sustainability of a floating PV system in an urban neighbourhood. As a matter of fact, structuring the framework as a step-by-step conceptual model proved itself to be a practical approach to assess the sustainability of the floating PV power plant. In addition, its specific methodologies provide a systematic and logical evaluation process where the suitability of a location is considered, the system's components analysed, and technical, economic, environmental, and social indicators are assessed with an integrated approach. Therefore, the third sub-question is positively answered, and the state-of-the-art framework can be recommended as a first decision-support tool to guide engineers in the sustainability assessment of urban floating solar technologies prior to installation.

The results are now further analysed to understand whether floating PVs can promote sustainable energy development in cities and to answer the fourth sub-question. The construction, and operation & decommission activities related to the implementation of a floating PV system in Camminghaburen cannot be considered fully sustainable. As a matter of fact, when looking at the assessment of technical, environmental, economic, and social indicators, not all the goals are met. The floating PV system is expected to be a source of water pollution due to metal corrosion and damages to the PV modules. More importantly, the residents of Camminghaburen are not willing to accept the installation of such an energy plant from a social and economic perspective. This means that inhabitants are concerned about the visual impact and the disruption of social leisure activities that the system would cause. Besides, they prefer private and public institutions to fully manage the costs of the floating solar plant, even if it means that they would not receive any direct economic benefit from it. As a result, although the technical indicators showed that the floating PV system would achieve optimal energy and economic performance, this sustainability assessment shows that implementing this type of solar installation in an urban neighbourhood would face major social and economic barriers in Camminghaburen, making it not sustainable. Such issues are expected to be the most relevant ones for a real-life floating PVs energy project in the built environment. It is reasonable to say that the floating PV system designed should not be installed in the Camminghaburen district of Leeuwarden.

6. DISCUSSION

In this section of the paper, the validity of applying the state-of-the-art decision-support framework developed in the theoretical framework to guide the sustainability assessment of a floating PV system in a residential neighbourhood is discussed. Therefore, the framework is reviewed to argue whether the conceptual model and the specific methodologies used have been effective tools to carry out such an assessment. The main objective of this discussion is to identify limitations and possible improvements for the decision-support framework and the methodologies used. In addition, the applicability of the state-of-the-art decision-support framework to a context other than Camminghaburen and Leeuwarden is argued.

Overall, the state-of-the-art decision-support framework designed is a valuable tool to guide engineers in the sustainability assessment of energy systems and floating PV plants. The conceptual model helps to implement the assessment in an energy project in an effective way by following a step-by-step procedure linked with the development stages. Nevertheless, when it comes to the application of methodologies necessary to select a suitable location and identify and analyse the indicators, three limitations are found. The first is related to using literature and reports reviews to identify and evaluate the indicators. In fact, the data and information generated from such a technique are only an approximate estimation of the real numbers and characteristics of the aspects or impacts under investigation for this fictional floating PV system. As a result, these kinds of data cannot provide reliable identification and analysis of the indicator, leading to possible errors and limitations. To deal with such an issue, the identification and evaluation of indicators should be supported by interviews with an expert in the field, who can suggest recently identified indicators and other reliable evaluation methods to generate realistic data and information. In addition, floating PV systems are a novel application of solar panels and all the possible aspects and impacts to them related have not been identified yet. Therefore, basing their identification on existing papers and reports does not lead to propose any new indicator related to floating PVs. Again, it would be important to interact with a floating PVs expert to identify new indicators and use more reliable evaluation methods. For this research project several companies, i.e., Ciel & Terre, HelioFloat, Ocean Sun, that operate in the floating PVs sector were contacted to arrange an interview with an expert. Nevertheless, it was not possible to carry out an interview with an expert because they were not available mainly due to COVID-19 complications.

The second limitation concerns the lack of equipment and financial resources that are necessary to examine specific indicators, especially those related to the biological conditions of the water body. In fact, several important indicators, i.e., the salinity of the water, levels of oxygen, and algae growth index, cannot be analysed, meaning that they are not identified and considered for the evaluation of this energy project. This is mainly due to the lack of resources and equipment available. Considering these types of indicators is important to evaluate how the water body may react during and after the installation of the floating solar system. Similarly, such aspects are essential to understand how the energy system may be influenced by the biological characteristics of the water body. To deal with this limitation, it is necessary to collaborate with specialized agencies that can provide the right equipment to generate these kinds of data and information.

The third limitation is related to the use of SketchUp Pro to analyse the shading patterns and visually evaluate some of the technical indicators. As a matter of fact, although the 3-D design software allows recreating a model of the location, the precise scale and position of the surrounding elements, i.e., trees and buildings, is not exactly reported. This can lead to unrealistic evaluation of the suitability of the location and of some technical indicators related to the construction and operation & decommission stages. Again, such a limitation is due to the lack of professional tools and analysis software, like HelioScope. Therefore, this issue can be solved by using modelling software specialized in the analysis of solar energy systems. However, subscribing to these types of software is expensive, which is the reason why they were not used in this research project.

On the other hand, it is important to mention that the evaluation carried out with PVSyst 7.2 and the survey provided realistic and valuable data and information. This suggests that these methodologies can be proposed in any other sustainability assessment of a floating PV system. In this regard, the structure of the state-of-the-art decision support framework can be easily implemented in any other energy project where the sustainability assessment of a floating PV plant must be carried out. However, not all the specific methodologies used to identify and evaluate the suitability of the location and some of the indicators should be considered as reliable. As a result, it is reasonable to say that this research project offers a good framework but fails to propose the correct procedures to identify and evaluate some of the aspects and impacts of a floating PV system. Therefore, the conceptual model designed can work as a preliminary framework to guide engineers in the sustainability assessment of any floating PV technologies in urban areas prior to installation but more precise and powerful modelling software is needed to make it the first universally recognized tool for the evaluation of this SET.

7. CONCLUSION

This research project emphasizes the importance of carrying out a sustainability assessment to evaluate prior to installation whether floating PV systems can be implemented in urban neighbourhoods and promote sustainable energy development. To perform and implement in an energy project a sustainability assessment, a decision-support framework must be used. Since current tools have some limitations, namely the lack of the technical dimension, the lack of specific methodologies, and the fact that it is not clear when to implement such frameworks during the development stages on an energy project, a state-of-the-art decision-support framework is designed.

In the theoretical framework this tool is elaborated and the first sub-question, namely *how is a decision-support framework implemented in an energy project to carry out a sustainability assessment of a power plant prior to installation,* is answered. In fact, the framework is presented as a conceptual model that guides engineers to carry out the sustainability assessment of a power plant as a step-by-step procedure throughout the three development stages of an energy project. To implement the framework, there are six steps to be followed in accordance with the stage of the project. First, for the planning stage, it is necessary to select a suitable location for the installation of the power plant. The second step consists of choosing the ideal components for the system. Next, to conclude the planning stage the goals sought to be achieved must be defined. Subsequently, the construction stage starts, and the corresponding steps of the framework require to identify sustainability indicators, evaluate them to generate quantitative data and qualitative information and finally assess them. This process is repeated for the last stage of an energy project, namely the operation & decommission. Therefore, the fourth, fifth, and sixth steps of the framework are carried out twice, once for the construction stage and once for the operation & decommission one.

The second sub-question, namely *what methodologies must be used to select a suitable location and the system's components, and identify, evaluate and assess the aspects and impacts of a floating*

PV system, is answered in the methodology chapter. In fact, specific methodologies necessary to select a suitable location and the right components, and identify, evaluate and assess indicators are elaborated in chapter 3. For the selection of the location precise political, socio-economic, and physical criteria must be met. Therefore, online research and digital and empirical spatial analysis are proposed as methods to evaluate whether a location has the right conditions for the installation of a floating PV system. To choose the system's components technical and economic criteria must be met. Therefore, online research and SketchUp Pro are used as methods to evaluate whether the technologies respect the criteria proposed. Subsequently, the procedure to define the goals sought to be achieved is described. This consists of defining goals on the basis of three United Nations SDGs, namely SDG 7, 11, and 13. These SDGs focus on defining sustainable energy development in cities as the implementation of an energy system in an urban environment while considering its energy-related issues, ensuring economic growth and social inclusion and participation in the decision-making processes, and minimizing the negative effects on the environment. Therefore, the goals are focused on these principles. Next, the method that concerns the identification of sustainability indicators is explained. Such a method consists of reviewing literature and companies' reports in order to identify relevant indicators as technical, economic, environmental, and social aspects and impacts. The specific methods for the evaluation of indicators are thus elaborated for each sustainability dimension. The technical ones are analysed through SketchUp Pro, PVSysts 7.2, and literature and reports review. The economic indicators are evaluated using PVSyst 7.2, a survey, and literature and reports review. The environmental ones are analysed through literature and reports review. The social indicators are evaluated using a survey and literature and reports review. Finally, the assessment method is elaborated as a juxtaposition analysis where the data generated are related to the goals defined to understand to what extent they can be achieved. In the case a goal is not met, the floating PV system cannot be considered as a power plant that promotes sustainable energy development in a city.

The third sub-question, namely *can a decision-support framework assess with specific methodologies the sustainability of a floating PV system in an urban neighbourhood,* is practically answered in chapters 4 and elaborated 5 and 6. As a matter of fact, the decision-support framework and its methodologies are applied in a fictional energy project where a floating PV system is planned to be installed in an urban neighbourhood. This is done to test and validate the framework and its methodologies. Since it was possible to carry out an integrated sustainability assessment, it is reasonable to say that the tool and procedures proposed can assess the sustainability of a floating PV system in a city. Nevertheless, this is only partially true, as in the discussion it is highlighted that the methods based on literature and reports review and the use of SketchUp Pro can lead to generating inaccurate data.

Finally, the fourth sub-question, namely *can a floating PV system be sustainable in the urban neighbourhood selected,* is answered in the analysis of the results. Such an analysis suggests that a floating PV system cannot be sustainable in the urban district selected mainly due to the social opposition of the inhabitants and their unwillingness to pay for the installation.

As a result, to answer the main research question, namely *how can the sustainability of a floating PV system in an urban neighbourhood be assessed using a decision-support framework and specific methodologies,* a final decision-support tool is developed for assessing the sustainability of floating PV systems in cities. This tool is developed from the combination of the state-of-the-art framework and the specific methodologies applied and it is shown in figure 31.

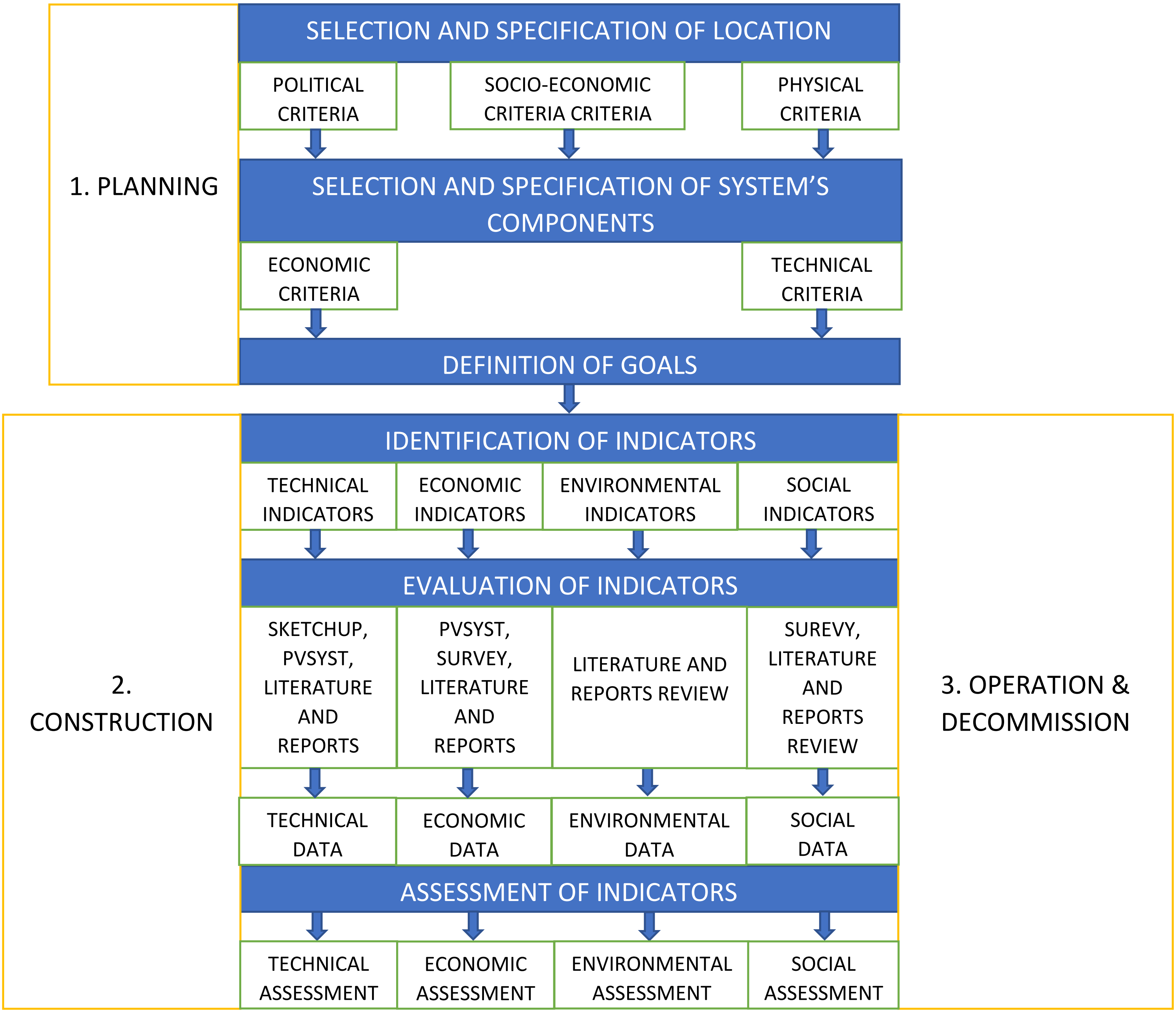

Figure 31: The final decision-support framework that includes the specific methodologies used to select a suitable location and choose the right components, and identify, evaluate, and assess the indicators for the sustainability assessment of a floating PV system in an urban neighbourhood.

By following the steps and methodologies proposed in this framework it is possible to carry out a sustainability assessment of a floating PV system in a city. The research question is thus answered with the development of this conceptual model, which includes the steps and specific methodologies needed to assess the sustainability of floating PV systems. If the methodologies are correctly enhanced and the limitations tackled, this decision-support framework can be a preliminary analysis for the application of this kind of solar power plant in cities. As a result, this framework can be used to properly answer whether floating PVs can promote sustainable energy development in cities, but more accurate and reliable investigation and evaluation methods should be used.

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