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Methodology for Analysing the Social Cost of Energy (SCOE) for a floating photovoltaic plant (FPV) in Spain

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Abstract. The growing need of the global society to harness renewable resources has resulted in a heightened curiosity to adopt innovative technologies in novel settings. An illustration of this phenomenon can be seen in offshore floating solar power facilities (FPV). As of August 2020, cumulative installed floating solar PV capacity was over 2 GW in 338 active projects and in 35 countries worldwide [1]. The rising interest in FPV is boosted by its decreasing LCOE (Levelized Cost of Energy), which refers to the estimated revenue required to build and operate a generator over a specified cost recovery period [2], as records indicate that FPV could reach competitive prices of 0.05 USD/kWh by 2030 and 0.04 USD/kWh by 2050 [3] as cited in [1]. The aim of the paper is to introduce a methodology developed to evaluate the societal consequences and externalities linked with the implementation of a floating photovoltaic plant in Spain, specifically in a region in north-western Spain. The employed methodology is based in analysing the Social Cost of Energy (SCOE), which integrates a multifaceted approach. It combines economic valuation techniques, environmental impact assessments, and social cost-benefit analysis for the quantification of the holistic impact of the OFV project. The findings highlight the significance of considering social costs alongside traditional economic metrics when assessing renewable energy projects such as floating photovoltaic plants. In conclusion, this research underscores the necessity of incorporating social cost considerations into energy policy and decision-making processes to ensure the achievement of sustainable and socially responsible energy transitions in Spain.

Key words. Social Cost of Energy, Social Impact, Sustainable Development, Methodological Framework, Floating Photovoltaic.

1. Introduction

A floating photovoltaic system, also known as FPV, refers to a type of photovoltaic facility that is specifically designed to be installed on water bodies [4], including both inland waters and the open see.

Studying PFV systems holds paramount importance as they represent a promising avenue for expanding renewable energy capacity, particularly in regions with limited land availability, such as densely populated countries and islands [5]. With the projected installed capacity expected to reach around 30,000 MW by 2030 [6], comprehensive research into floating photovoltaic technology is essential for addressing sustainable development goals on a global scale.

Research on floating photovoltaic systems has demonstrated their ability to mitigate environmental impacts by reducing water evaporation, which can be particularly beneficial in regions facing water scarcity challenges. Furthermore, these systems help improve water quality in reservoirs and lakes by providing shade, thereby limiting algae growth and enhancing ecosystem health. The environmental benefits of floating solar installations extend beyond energy generation, highlighting their potential to contribute to sustainable water management practices [7].

Among FPV's trends, a particularly relevant one is their emergence in port areas, serving self-supply purposes and contributing to port electricity demand coverage. However, the study of potential offshore locations necessitates careful consideration of their impact on maritime traffic and navigation safety. Additionally, a trend toward the creation of combined technology power plants is observed, where FPV installations share infrastructures with other marine and offshore wind energy technologies to optimize investment and operational efficiency [1].

Spain has a high solar energy resource and a large water surface area suitable for the deployment of FPV systems [8], given its extensive coastline, reservoirs, and inland water bodies. Analysing the social cost of energy in this context is crucial for understanding the broader implications of implementing such systems. By assessing factors like environmental impact, land use, economic feasibility, and social acceptance, researchers can provide valuable insights into the overall sustainability and societal implications of floating solar installations in Spain. This analysis is essential for policymakers, energy planners, and stakeholders to make informed decisions that balance energy needs with environmental conservation and social welfare in the region.

2. Designed methodology

Calculating the Social Cost of Energy (SCOE) for a floating photovoltaic system involves a comprehensive methodology that considers various factors to assess the broader societal implications of such installations. The designed methodology encompasses a multidisciplinary approach, integrating environmental, economic, and social parameters to evaluate the full spectrum of costs and benefits associated with floating solar projects. Life cycle assessment techniques are intended to quantify environmental impacts. Additionally, economic models are aimed at estimating costs and benefits over the system's lifespan. Furthermore, social impact analysis assesses the effects on communities and stakeholders. By combining these methodologies, we can provide a holistic understanding of the SCOE for floating photovoltaic systems, aiding policymakers, and stakeholders in making informed decisions regarding sustainable energy transitions.

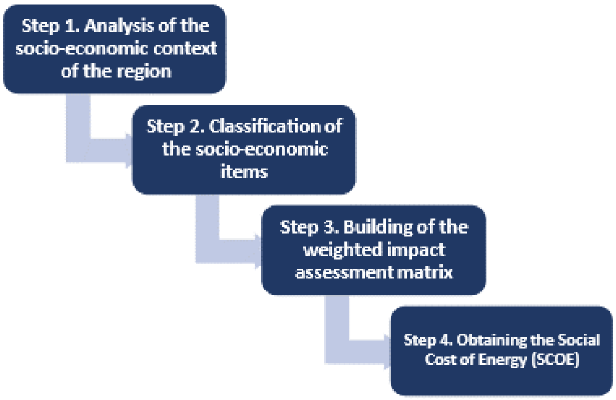

Fig. 1. Diagram representing the methodology developed to obtain the SCOE of an FPV system.

The procedure for determining the SCOE of a FPV system consist in four main steps, which are illustrated in Fig. 1.

A. Analysis of the socio-economic context of the region.

To determine the SCOE associated with the floating photovoltaic systems planned to be installed in a region, it is crucial to analyse the socio-economic context of the area.

Within this comprehensive analysis, various facets are considered, encompassing an examination of regulatory frameworks governing the utilization of public and private domains, both maritime and terrestrial, for renewable energy projects. Additionally, a focus is placed on the primary economic activities within the deployment region, notably fishing, maritime traffic, and tourism. The presence of environmentally protected zones, areas of cultural significance, and existing or planned energy infrastructures further enriches the assessment, aiming to identify potential synergies and foster sustainable development initiatives. Through environmental analysis, the evaluation extends to understanding ecological implications and conservation endeavours within the region.

The principal socio-economic factors that must be considered are precisely enumerated as follows:

1) *Population.* The population density of the affected municipalities is examined, and an assessment is made as to whether they are experiencing population growth or decline.
2) *Employment.* For each municipality under study, the total number of jobs as well as jobs by sector are observed.
3) *Environment.* The most significant legally protected environmental areas to consider are examined with the aim of avoiding encroachment during the project development stage. The studied areas are as follows:
    - Natura 2000
    - Protected Natural Spaces
    - Public Utility Mounts
    - Spanish Network of Marine Protected Areas
    - Important Areas for Bird and Biodiversity Conservation
    - Areas Protected by International Instruments such as RAMSAR and ZEPIM areas, or Biosphere Reserves.
4) *Cultural Heritage.* Areas of cultural significance, such as archaeological zones and cultural heritage assets, are thoroughly examined and analysed.
5) *Maritime-terrestrial Public Domain.* It is studied whether the FPV system is located outside the areas of legal servitude and influence.
6) *Maritime Spatial Planning.* The suitability of the location of the FPV system is analysed in accordance with the Maritime Spatial Planning, elaborated according to Royal Decree 363/2017, of April 8 [9], which transposes Directive 2014/89/EU of the European Parliament and of the Council, of July 23, 2014 [10].
7) *Fishing activities.* The activities related to fishing in the vicinity of the renewable installation are studied. Among the activities are:

- Marine Reserves
- Location of the main fishing grounds
- Fishermen's Guilds in the area
- Aquaculture activities

8) *Maritime Traffic.* Considering different industries such as cargo transportation, passenger transportation, and fishing, which are quantified in terms of routes per square kilometre per year. Moreover, the estimated count of overall vessels in the areas under examination is determined, measured in the average number of hours per square kilometre per year.
9) *Other Coastal Activities.* Other activities carried out along the coast of the studied areas are examined with the aim of considering them and promoting synergies that may positively impact the population. Thus, the following activities are analysed:
   - Dredging Stations
   - Water Treatment
   - Desalination Plants
   - Microalgae and Spirulina Production
10) *Energy Infrastructures.* A crucial aspect when developing renewable energy projects is to consider the availability of connection to the grid. Additionally, the existence and planning of renewable energy installations in the study areas are examined, which should be considered for future synergies.
11) *Landscape Impact.* The visual influence that the population might experience due to the renewable installation should be considered by taking into consideration the beaches that are in proximity.

B. *Classification of the socio-economic items*

Classifying the socio-economic items into various categories holds significant importance in both research and decision-making processes. This practice enables a structured organization, systematic analysis, and meaningful interpretation of intricate data. By effectively categorizing diverse socio-economic factors such as population trends, environmental considerations, cultural heritage assessments, and economic activities, we obtain a comprehensive understanding of the multi-faceted impacts and interactions within the FPV context. This classification process further aids in identifying patterns, relationships, and trends across different dimensions, thereby facilitating the extraction of valuable insights and the formulation of well-informed strategies.

Our methodology involves a systematic approach to classify the socio-economic items into different 24 categories to analyse thoroughly. The 24 categories are as follows:

1) *Levelized Cost of Energy.* Is a metric used to calculate the cost of energy over the lifespan of a project. It considers factors such as total investment, operation and maintenance costs, and energy production. However, the LCOE may vary depending on project-specific considerations.
2) *Greenhouse Gas Emissions.* Assessed by considering the substitution of fossil fuels and coastal activities.
3) *Energy Efficiency.* Evaluates the relationship between useful energy and total energy used, including losses in transmission and distribution.
4) *Energy Resources.* Refer to the costs associated with energy generation and consumption, as well as integration with other systems.
5) *Human Health Impact*. Considers factors such as air pollution and occupational health risks.
6) *Biodiversity Impact*. Includes factors like loss of habitats and pollution.
7) *Climate Change*. Primarily considers greenhouse gas reduction.
8) *Energy System* Resilience. addresses diversification and redundancy of energy sources, as well as the system's ability to recover from adverse events.
9) *Social and Economic Inequality.* Evaluates impacts on employment, tourism, and fishing.
10) *Employment Generated.* Considers sectoral distribution and employability in renewable projects.
11) *Associated Risks (accidents, natural disasters).* Consider climate change effects and local activities.
12) *Energy Resources Availability.* Evaluates the economic and environmental impacts of relying on specific sources.
13) *Technological Maturity.* Represents energy technology efficiency and development.
14) *Governmental Policies and Regulations.* Focus on environmental regulations and economic activities.
15) *Workforce Education and Training.* Assesses the educational and training levels of workers in the energy sector, as well as the resources and time dedicated to their education and training. It also considers the presence of higher education institutions in the area.
16) *Community Participation and Acceptance.* Examines the presence of similar projects in the area and the potential for community involvement in those projects.
17) *Supply Chain and Logistics.* Considers the level of industrialization in the province and the coastal activities related to the energy sector.
18) *Transportation Infrastructure.* Evaluates the availability of transportation in the area and the potential for improving existing infrastructure, which can impact the well-being of the population.
19) *Long-Term Sustainability.* Is defined as the ability to achieve sustained economic prosperity while also protecting the planet's natural systems and ensuring a high quality of life for people. In this context, it encompasses the impact on the landscape and environment, as well as the development of coastal activities.
20) *Circular Economy and Recycling.* Considers recycling and reuse projects that are connected to the installation in the area.

21) *Energy Security.* Considers the duration and frequency of energy supply interruptions, the condition of the power grid, and the security of telecommunications.
22) *Integration with other Energy Systems.* Evaluates the planning of networks and, specifically, the supply chain and logistics to identify synergies with neighbouring installations.
23) *Adaptation Capacity to Future Changes.* Examines the ability to adapt to changes in socio-economic, environmental, technological, and training needs.
24) *Land Use and Conflicts.* Considers the population of the area, the impacts on the natural and landscape, and the compatibility with other coastal and fishing activities in the study area.

This classification facilitates the interpretation of the socio-economic items in a particular location by providing a systematic framework that allows for a more nuanced understanding of the various factors influencing the socio-economic landscape.

C. Building of the weighted impact assessment matrix

The systematic approach involved in constructing a weighted impact assessment matrix, which incorporates the principal socio-economic factors outlined previously, necessitates a methodical and rigorous process. In the initial stages, each socio-economic variable is meticulously identified and classified, considering various dimensions such as population density, employment, environmental considerations, cultural heritage, and other factors delineated in the study parameters. This comprehensive categorization is achieved through a meticulous compilation of relevant data for each category, which entails exhaustive literature reviews.

Once the requisite data has been gathered, the next step involves formulating a weighting system that assigns relative significance to each socio-economic factor based on the following:

1) *Intrinsic importance*
2) *Breadth of impact*
3) *Duration of the impact*

These weighting coefficients are derived from the careful assessment of each variable that affects the 24 study parameters, thereby reflecting their respective contributions to the overall socio-economic landscape.

After the establishment of the weighting coefficients, the collected data undergoes a normalization process to ensure uniformity across the diverse socio-economic factors. This normalization process involves transforming the raw data into a standardized scale that ranges from 0 to 100. By doing so, meaningful comparisons and computations can be made across different socio-economic factors.

Subsequently, the weighted impact assessment matrix is formulated by multiplying the normalized data for each socio-economic factor by its corresponding weight coefficient. This step results in the generation of a comprehensive matrix, wherein the weighted values represent the relative importance and impact magnitude of each socio-economic factor within the project area.

D. Obtaining the Social Cost of Energy (SCOE)

The Social Cost of Energy (SCOE) is calculated by adding up the final evaluation of each of the 24 factors, utilizing the previously described weighted impact assessment matrix. This matrix serves as a comprehensive tool for assessing the multifaceted socio-economic landscape surrounding a project area, enabling a nuanced understanding of the diverse influences at play.

Through this systematic approach, the SCOE encompasses the cumulative effect of various socio-economic considerations, providing stakeholders with a synthesized metric to measure the overall impact of a project on the adjacent population.

To interpret the SCOE, one must grasp its numerical range and significance in relation to the well-being of the local community. The scale ranges from 0 to 100, where 100 represents a profoundly positive impact on the nearby population, 0 signifies a detrimental effect, and 50 denotes a neutral impact. This scale allows stakeholders to discern the extent to which a project may contribute to or detract from the socio-economic fabric of the surrounding area. Furthermore, the SCOE offers a standardized metric that facilitates comparisons across different projects, regions, or temporal intervals, fostering informed decision-making and strategic planning.

A high SCOE indicates that the project is expected to generate significant socio-economic benefits for the adjacent population, such as job creation, infrastructure development, or improved community well-being. On the other hand, a low SCOE suggests that the project may pose substantial risks or adverse effects on the local socio-economic landscape, necessitating careful mitigation measures or re-evaluation of project parameters.

3. Conclusion

The developed methodology for evaluating the Social Cost of Energy (SCOE) associated with floating photovoltaic plant (FPV) installations in Spain presents a robust framework. Incorporating 24 socio-economic factors and employing a weighted impact assessment matrix, this approach allows for a systematic examination of the potential impacts of FPV projects on local communities and ecosystems, offering a standardized metric with SCOE values ranging from 0 to 100. This facilitates informed decision-making and strategic planning for renewable energy initiatives, leveraging a holistic assessment that encompasses variables like population density, employment, cultural heritage, and maritime traffic. Such comprehensive analysis empowers stakeholders to identify optimal project parameters and mitigation strategies, enhancing positive outcomes and minimizing adverse effects, with the methodology's scalability and adaptability rendering it applicable to FPV projects globally, thereby contributing to sustainable energy transitions on a global scale.

Despite its strengths, it is imperative to recognize the limitations of the methodology. These include the inherent subjectivity in weighting socio-economic factors and the potential variability in data quality and accuracy. While the SCOE metric offers a valuable tool for comparative analysis, its utility is enhanced when complemented by qualitative assessments and stakeholder engagement, ensuring a nuanced understanding of project impacts. Moreover, interdisciplinary collaboration and ongoing refinement are necessary to address evolving socio-economic dynamics and stakeholder preferences effectively. By acknowledging these limitations and leveraging the methodology's strengths, stakeholders can navigate the complexities of renewable energy development with greater confidence, advancing toward a more sustainable and equitable energy future.

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