

# Environmental impact study of the NOOR 1 solar project on the Southern Region of Morocco

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**Abstract.** Morocco is leading the charge towards a more sustainable future through its investments in Renewable Energy. The NOOR 1 solar project in Ouarzazate serves as a shining example of this commitment, with a planned capacity of 160 MW and the potential to provide energy to over 1 million people. This study delves into the impact of this ground-breaking project on the environment and biodiversity in the southern region, as well as its role in combating global warming. The results show that the project has both positive and negative impacts, but its innovative concentrated solar power technology is the driving force behind these changes. Despite causing loss of native vegetation and wildlife habitat, changes to water resources and air quality, the NOOR 1 project also has many benefits such as reducing greenhouse gas emissions, enhancing energy security, providing economic benefits, improving access to electricity, and providing educational opportunities. The research emphasizes the crucial need to assess future renewable energy projects in a holistic manner, considering both environmental preservation and progress. This means taking into account both the positive and negative impacts that such projects may have on the environment and biodiversity and implementing measures to mitigate the negative impacts while maximizing the positive ones. The study suggests that a well-planned and executed renewable energy project can bring about significant benefits, such as increased energy security and economic benefits, while still being mindful of preserving the natural environment. By carefully balancing environmental preservation and progress, the study argues that renewable energy projects can help create a sustainable future for all.

**Keywords:** Energy transition / environmental impact / renewable energy / NOOR 1 (concentrated solar power) project

## 1 Introduction

The escalating demand for energy coupled with the need to curtail greenhouse gas emissions has sparked an increased interest in renewable energy, particularly in developing nations like Morocco. To meet its energy requirements and spur economic development, Morocco has launched a variety of tactics and initiatives aimed at boosting its usage of renewable energy. One of these schemes is the NOOR 1 solar project located in Ouarzazate, in the southern region of Morocco. In a bid to generate 52% of its electricity from renewable sources by 2030, the Moroccan government has set ambitious objectives for renewable energy development [1].

One of the main approaches that Morocco has adopted to promote its use of renewable energy is the introduction of the National Energy Strategy, which seeks to develop a diversified energy mix with a focus on renewable energy. This approach includes the implementation of large-scale renewable energy projects, such as the NOOR 1 solar project in Ouarzazate. Additionally, Morocco has established different policies and incentives to encourage the adoption of renewable energy, such as the feed-in tariff system that offers a fixed price for electricity generated from renewable sources. This system is designed to attract private investments in renewable energy projects, including the NOOR 1 solar project.

Morocco has also embarked on several ambitious projects, such as the “Solar Plan,” which is a \$9 billion investment aimed at developing 2 GW of solar power capacity, and the “Green Morocco Plan,” which is a \$2 billion investment aimed at developing wind, hydro, and solar power capacity. The Moroccan Agency for Solar

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Energy (MASEN) has also been created to promote the use of solar energy and develop large-scale solar energy projects, such as the NOOR 1 project. As a result, Morocco has become a leading nation in renewable energy in Africa and the Middle East.

The NOOR 1 project is a Concentrated Solar Power (CSP) facility with a projected installed capacity of 160 MW, capable of providing energy to over 1 million people. Although renewable energy projects like this one are expected to have a positive impact on the environment by reducing greenhouse gas emissions and improving energy security, they also have the potential to cause negative impacts on the environment and biodiversity.

The objective of this research is to assess the potential effects of the NOOR 1 solar project on the environment and biodiversity in the area and how they contribute to combatting global warming. Although renewable energy projects, such as NOOR 1, are often promoted as a way to balance economic growth with environmental preservation, it is essential to ensure that these initiatives do not harm the environment and biodiversity. This investigation is critical for several reasons. Firstly, the Southern Region of Morocco, where the NOOR 1 project is situated, is an ecologically vulnerable area with rich biodiversity, and it is necessary to comprehend how the project may impact the ecosystem. Secondly, NOOR 1 is one of the most significant CSP projects globally and serves as a model for the Moroccan government. Consequently, analysing its environmental impact may benefit other regions and countries considering similar projects. Lastly, NOOR 1 is part of Morocco's ambitious renewable energy goal, and this research can ensure that this target is achieved in an eco-friendly manner.

This paper provides an innovative and comprehensive case study of the environmental impact of the NOOR 1 solar project, which is a unique concentrated solar power (CSP) plant located in the southern region of Morocco. The research's originality lies in its case study approach, which allows for an in-depth examination of the particular impact and benefits of CSP technology employed in the project. Moreover, the study emphasizes the importance of assessing the potential environmental impacts and advantages of renewable energy projects and implementing measures to mitigate negative impacts and maximize benefits. This methodology is crucial in ensuring the sustainability of renewable energy projects and their effectiveness in combating climate change. The study also provides a holistic view of the trade-offs between environmental impact and benefits, which may serve as a valuable resource for policymakers, researchers, and practitioners working in the renewable energy sector. Furthermore, this study is unique in its focus on the environmental impact of renewable energy projects in the Southern Region of Morocco, which has received less attention compared to other regions.

In Morocco, there is a tendency to concentrate on studying the negative impacts of some renewable energy technologies, such as photovoltaics, while neglecting other technologies like CSP and their advantages.

For example, several studies have been conducted on the impact of dust on solar energy technologies, particularly in desert regions of Morocco. The study made by El-Mansouri et al. examines the impact of dust on photovoltaic performance in the desert region of Morocco, by performing experiments on solar panels that were exposed to different dust concentrations. The study found that dust accumulation on the surface of the solar panels resulted in a significant reduction in energy output and an increase in the surface temperature of the panels [2].

Also, Boukhalfa et al. have reviewed the literature on the impact of dust on photovoltaic performance in desert environments and provided an overview of the various factors that affect the accumulation of dust on solar panels, including wind speed, wind direction, and relative humidity. The study also includes an extensive literature review on the methods used to mitigate the impacts of dust on photovoltaic performance, such as washing, cleaning, and coating techniques [3].

Another study made by Ait-Kadi et al. examines the impact of dust on photovoltaic performance in the desert region of Morocco, and provides a detailed analysis of the various factors that affect dust accumulation on solar panels [4].

The study of Boukhalfa et al. discuss the importance of monitoring and forecasting dust storms, as well as the development of dust forecasting models, to help predict and mitigate the impacts of dust on solar energy systems. Additionally, the study highlights the need for further research on the impact of dust on different types of solar energy technologies, such as concentrated solar power, and the development of more effective cleaning and maintenance strategies to improve the performance and longevity of solar energy systems in desert environments [5].

The study authored by Boukhalfa et al. investigates the impact of dust on the performance of photovoltaic systems in desert environments, with a focus on the Ouarzazate solar power plant in Morocco. The authors note that the performance of photovoltaic systems can be significantly affected by dust accumulation, which reduces the amount of sunlight that reaches the solar panels, and found that dust accumulation on the solar panels led to a reduction in the efficiency of the photovoltaic systems. The study also examined the effectiveness of different cleaning methods for removing dust from solar panels [6].

In summary, these articles focus on perspectives on how dust affects the efficiency of photovoltaic systems in desert environments, emphasizing the significance of consistent cleaning and upkeep to ensure maximum performance. They also illustrate the harmful impact of dust on photovoltaic technologies in desert regions such as Morocco, underlining the need to address these concerns to enhance the effectiveness and sustainability of solar energy systems in such areas.

Conducting an environmental impact study of the NOOR 1 solar project in the Southern Region of Morocco is necessary for several reasons:

- Compliance with regulations: Environmental impact assessments (EIA) are commonly required for large-scale development projects such as the NOOR 1 solar project.

An EIA is a process used to identify and evaluate the potential environmental impacts of a proposed project and to develop strategies to mitigate these impacts.

- Environmental protection: the Southern Region of Morocco is an important area for biodiversity, and the NOOR 1 project is located in an ecologically sensitive area. An environmental impact study can help to identify and mitigate any potential negative impacts of the project on the environment and biodiversity in the region.
- Sustainability: The NOOR 1 project is part of Morocco's ambitious target to generate 52% of its electricity from renewable energy sources. Conducting an environmental impact study can help to ensure that this goal is met in an environmentally sustainable manner.
- Transparency and public engagement: Conducting an environmental impact study provides an opportunity for public engagement and transparency in the decision-making process for the project. It allows the public and stakeholders to understand the potential impacts of the project and provide feedback.
- Learning from past experiences: The NOOR 1 project is the first of its kind in the Southern Region of Morocco and it is considered a flagship project for the Moroccan government. Conducting an environmental impact study can provide valuable insights for other countries and regions considering similar renewable energy projects.

Although many studies on the environmental impact of renewable energy projects offer general information on the potential impacts of different types of renewable energy, they often lack detailed case studies of specific projects. This results in limited information on specific impacts, such as the effects on particular species or habitats. Moreover, many studies focus primarily on developed countries, creating knowledge gaps about the potential impacts of renewable energy projects in developing countries. Additionally, some studies provide only general information on the environmental impact of renewable energy, without delving into the specific impacts of various technologies, like concentrated solar power (CSP) technology.

Therefore, to make informed decisions about the development and implementation of renewable energy projects, policymakers require comprehensive information. They need to comprehend the potential impacts of a project on the environment and biodiversity, enabling them to formulate strategies to mitigate these impacts and guarantee the sustainable development of renewable energy projects. They must also strike a balance between economic development and environmental protection in the development of such projects. In addition, policymakers need to comprehend the potential of renewable energy projects to reduce greenhouse gas emissions and promote sustainable development. This understanding can assist them in aligning their energy policies with global efforts to combat climate change.

To summarize, it is important to study the environmental impact of the NOOR 1 solar project in the Southern Region of Morocco to gain an understanding of its potential effects on the environment and biodiversity in the area. Additionally, this research can provide valuable insights

for other regions and countries considering similar renewable energy projects. Ultimately, this type of research is critical for policymakers to make informed decisions about the development and implementation of such projects in a manner that is both environmentally sustainable and socially acceptable.

## 2 Literature review on the contribution of renewable energy to environmental protection

Renewable energy sources, such as solar, wind, hydro, and geothermal, have been widely recognized as key contributors to environmental protection. They have a lower environmental impact than fossil fuels and can help to reduce greenhouse gas emissions, air pollution, and dependence on finite resources.

In the natural resource economics literature, many authors have examined the long-term scarcity of oil reserves [7,8] and the polluting aspects of oil [9,10] separately. Because the use of polluting energy resources generates pollution that accumulates over time, an ecological disaster may occur at any time. Much of the anthropogenic climate change resulting from CO<sub>2</sub> emissions is irreversible over several centuries [11]. As a result, global warming will lead to severe degradation of tropical rainforests (e.g. the Amazon) and their carbon sequestration potential, the disintegration of Antarctic ice sheets with a rise in sea level of several meters over several centuries, large-scale release of methane from melting permafrost, and significantly amplify warming.

Irreversible ice sheet decay occurs when the global average temperature increase is about 1.5 °C above the pre-industrial level. The world will then continue to experience the irreversible effects of climate change, even if it reduces emissions from fossil fuels [12].

A detailed study of the environmental impacts of the massive use of fossil fuels has revealed that the most dangerous impacts are acid rain, deterioration of the ozone layer, and the greenhouse effect. It concludes that the best possible solution for these problems is the use of RE, which shows that there is a strong link between the use of RE and sustainable development [13]. The relationship between RE and sustainable development is also analyzed using a case study of the city of Saarbrücken in Germany, which in 1980 set up an energy program that won “the local government honour” at the Rio conference in 1992.

A study on solar energy confirms that using solar energy to heat buildings and heat water can prevent large amounts of GHG emissions. This study claims that GHG reduction is the main benefit of using solar energy and says that solar energy systems should be used as much as possible to achieve sustainable development while practicing the “think globally-act locally” principle [14]. Some studies approach this topic by focusing on specific regions or specific RE pathways to determine their impact on climate change mitigation. For example, several studies focus on developing and emerging countries, especially those with significant RE potential, such as the study that examined

the need to use RE in Turkey to reduce GHG emissions and contribute to limiting the level and intensity of climate change, especially as Turkey is geographically well located for the use of RE [15]. Some studies address the case of China, which is the largest CO<sub>2</sub> emitter in the world. These studies suggest that wind and solar energy can be used as effective tools to reduce CO<sub>2</sub> emissions and mitigate the harmful effects of climate change [16].

The International Renewable Energy Agency (IRENA) conducted a study that examines the advantages of renewable energy and focuses on its environmental benefits, particularly in solar, wind, hydro, and geothermal power [17]. According to the study, the use of renewable energy can result in significant reductions in greenhouse gas emissions, air pollution, and water consumption, while also contributing to energy security and job creation. Moreover, renewable energy is found to decrease water pollution and consumption, unlike fossil fuels that produce toxic waste and require more water. In conclusion, the study provides valuable insights into the environmental impact of renewable energy, emphasizing its role in mitigating climate change and resource depletion worldwide.

The National Renewable Energy Laboratory (NREL) carried out a comprehensive study that delves into the environmental advantages of renewable energy, with a particular emphasis on the reduction of water usage, water contamination, and air pollution. The research showed that renewable energy sources like solar and wind power require less water than fossil fuels, which is critical given the increasing water scarcity challenges that many regions face today. Additionally, renewable energy sources do not produce hazardous pollutants that can pollute water resources and endanger aquatic life [18]. The study also revealed that renewable energy has the potential to reduce air pollution since it does not generate air pollutants such as nitrogen oxides and sulfur dioxide, which are linked to fossil fuels. Furthermore, renewable energy sources do not emit greenhouse gases that cause global warming and climate change. Moreover, the study underscores the importance of considering the entire lifecycle of an energy system when assessing the environmental benefits of renewable energy. This includes the stages of production, transportation, installation, operation, and end-of-life, which can have varying environmental impacts.

Mark et al. present a comprehensive overview of various renewable energy types, including solar, wind, hydropower, geothermal, and bioenergy, delving into the scientific and technical principles underpinning each energy source [19]. The article also thoroughly explores the environmental advantages of these sources. Furthermore, the authors examine the obstacles and prospects of developing and executing renewable energy projects, such as acquiring a large land area, incurring high capital costs, and integrating renewable energy into the power grid. The article also provides a detailed examination of the policy and regulatory aspects of renewable energy development. This article serves as an invaluable resource for anyone interested in comprehending the current state of renewable energy and its potential to aid in the creation of a sustainable energy system.

Sovacool presents a comprehensive analysis of the environmental implications of diverse renewable energy technologies in their article. The study investigates the effects of solar, wind, hydropower, and bioenergy on the environment, and discusses the potential benefits of these technologies in terms of mitigating greenhouse gas emissions and improving air and water quality [20]. Additionally, the article emphasizes the possible adverse effects of these technologies and the importance of taking mitigation measures. Overall, the article offers a valuable resource for gaining an understanding of the environmental impacts of renewable energy technologies, as well as the trade-offs between positive environmental outcomes and negative impacts.

The article authored by Patel and colleagues provides a thorough summary of the environmental impacts linked with solar energy systems [21]. The paper evaluates the possible environmental impacts that can occur throughout the entire life cycle of these systems, ranging from the extraction of raw materials to the disposal of end-of-life solar panels. The article provides a detailed analysis of the potential environmental consequences of each phase, encompassing greenhouse gas emissions, changes in land use, water consumption, and the utilization of hazardous materials during the manufacturing process. Additionally, the article discusses different mitigation strategies that can be implemented to decrease the environmental impacts of solar energy systems. These strategies comprise the use of eco-friendly materials, recycling and repurposing of solar panel parts, and the development of efficient end-of-life disposal techniques.

In their article, Al-Tabbaa and co-authors present an extensive evaluation of the environmental effects that Concentrated Solar Power (CSP) technology may have on arid regions [22]. The study covers the entire life cycle of CSP systems, starting from raw material extraction and manufacturing, and continuing through operation, maintenance, and decommissioning phases. The authors also discuss the potential effects on local biodiversity and ecosystem services. Moreover, the article explores various mitigation measures that could be implemented to diminish the environmental impact of CSP technology, such as utilizing more efficient technologies, alternative cooling methods, and adopting eco-friendly manufacturing processes. In conclusion, the article delivers essential insights into the prospective environmental consequences of CSP technology, underscoring the necessity of meticulous planning and management to ensure that the technology is deployed in a manner that is environmentally sustainable. While the article examines various mitigation measures that can be employed to reduce the environmental impacts of CSP technology, it does not discuss the economic feasibility or practicality of implementing these measures. Also, the study mainly discusses the potential negative impacts of CSP technology, but does not thoroughly explore the positive environmental benefits of this renewable energy source, such as its potential to reduce greenhouse gas emissions and air pollution.

The scholarly article authored by Roshan et al. intends to conduct a thorough analysis of the environmental consequences of various renewable energy technologies in

the Mediterranean region [23]. The article encompasses diverse forms of renewable energy, and scrutinizes their environmental ramifications at every stage of their life cycle, starting from raw material acquisition to final disposal. However, the article is limited in that it does not present any new primary research or data, instead relying on existing studies which may have limitations and biases. Furthermore, although the article briefly mentions mitigation measures, it does not provide a comprehensive discussion of how to reduce the environmental impacts of renewable energy technologies in the Mediterranean region. Another study made by Harrison et al. examines the environmental impact of various renewable energy systems and compares them to traditional fossil fuel-based energy systems [24]. The paper concludes that, overall, renewable energy systems have lower environmental impacts than traditional fossil fuel-based energy systems. However, the specific environmental impacts vary depending on the type of renewable energy system. For example, wind and solar energy systems have lower greenhouse gas emissions and land use impacts compared to bioenergy systems, while hydroelectric systems have higher impacts on freshwater ecosystems. The authors also note that the environmental impacts of renewable energy systems can be reduced through careful planning and implementation. For example, selecting renewable energy systems with lower environmental impacts, using environmentally friendly materials in construction, and minimizing land use and water use impacts through responsible siting and operation practices. Overall, the paper provides a comprehensive overview of the environmental impacts of renewable energy systems and highlights the importance of considering these impacts when evaluating the sustainability of different energy sources.

In their review paper, El Fadel et al. thoroughly investigate how dust deposition affects the efficiency of solar panels and its impact on energy generation, particularly in desert regions [25]. The paper covers the sources of dust accumulation on solar panels, including natural occurrences such as dust storms and human activities like construction and agriculture. The authors explain that dust deposition can reduce solar panel efficiency through mechanisms like decreased sunlight exposure and increased panel temperature, resulting in decreased power output. Furthermore, the paper examines various methods and technologies that have been developed to mitigate the impact of dust deposition, including passive solutions like inclined panel mounting and active techniques like water or air-based cleaning systems. The authors underscore the importance of addressing dust deposition on solar panels, particularly as the use of solar energy continues to increase worldwide. They recommend continued research and development of effective dust mitigation techniques to ensure that solar panels remain efficient and long-lasting, and to sustain the growth of solar energy as a renewable source.

Over the past few years, there has been an increasing focus on utilizing renewable energy sources in Africa to combat energy poverty and minimize greenhouse gas emissions. Numerous African nations have established ambitious goals for renewable energy deployment and have

established policies and initiatives to encourage the development of renewable energy ventures.

Specifically, there have been numerous investigations into the ecological effects of renewable energy projects in Africa, particularly regarding solar and wind power ventures. These studies have analyzed the potential environmental consequences of renewable energy projects, such as impacts on biodiversity, land usage, and water resources.

In a notable study by Roshan et al., presents an overview of the renewable energy industry in Africa, highlighting the growing attention towards employing renewable energy sources to address energy poverty and climate change [26]. The authors address the environmental impact assessment process and its application to renewable energy projects in Africa, highlighting the obstacles faced such as inadequate data, insufficient resources, and limited technical expertise. Moreover, the paper delves into an examination of the current literature on the environmental impact of renewable energy projects in Africa, particularly solar and wind power projects. The authors analyze the potential effects of these projects on biodiversity, land use, and water resources, while also discussing different strategies that have been proposed to mitigate these impacts.

Ultimately, the authors suggest that enhancing data collection and sharing, as well as increasing technical expertise, could aid in overcoming the obstacles faced by environmental impact assessments in the region.

Additionally, there are other studies that focus on specific renewable energy technologies and their environmental impact in Africa. For example, in a study conducted by B.K. Sovacool, the potential environmental impacts of large-scale wind power projects in Africa were investigated [27]. The author reviews existing literature on the subject, discussing both positive and negative environmental impacts associated with wind power projects. While wind turbines do not emit greenhouse gases during operation, they may cause bird and bat mortality and habitat fragmentation. In addition, large-scale wind power projects may require significant land use, which could result in land degradation and soil erosion. The paper also explores the socio-economic impacts of wind power projects, including their potential effects on local communities and indigenous populations. The author stresses the importance of engaging with local communities and involving them in the decision-making process for wind power projects to ensure their acceptance and success, as well as the sustainability of renewable energy development in the region.

Al-Tabbaa et al. conducted a case study to evaluate the environmental impacts of the NOOR Solar Complex, a large-scale solar power plant in Morocco [28]. The study provides valuable insights into a specific renewable energy project and evaluates the effectiveness of implemented mitigation measures. However, limitations and criticisms of the study include the absence of a comparison with the environmental impacts of other renewable energy projects in the region, making it difficult to assess the relative sustainability of different types of renewable energy projects. Additionally, the study lacks a clear description

**Table 1.** GHG emissions from the energy sector in Morocco (2010–2014) [29].

| Emitted gases              | GHG emissions in GWP |        |
|----------------------------|----------------------|--------|
|                            | 2010                 | 2014   |
| CO <sub>2</sub>            | 46 626               | 53 923 |
| CH <sub>4</sub>            | 27                   | 27     |
| N <sub>2</sub> O           | 2                    | 2      |
| Fluorinated gases          | N/A                  | N/A    |
| Total en CO <sub>2</sub> e | 47890                | 55249  |
| NO <sub>x</sub>            | 165                  | 184    |
| CO                         | 230                  | 206    |
| COVNM                      | 53                   | 61     |
| SO <sub>2</sub>            | 135                  | 165    |

of the methodology used to assess the environmental impacts of the NOOR Solar Complex, which may hinder the ability of other researchers to replicate the study or assess its validity.

By analyzing the environmental impact of the NOOR 1 Solar project in the Southern Region of Morocco, this study contributes to the existing literature on the environmental impact of renewable energy projects in Africa. It emphasizes the significance of taking into account the environmental consequences of renewable energy projects in Africa to achieve sustainable development. The NOOR 1 solar project analysis is in line with other contemporary studies on renewable energy and the environment in Africa.

\* Greenhouse gas emissions from the energy sector in Morocco

In the energy sector, GHG emissions are derived particularly from (Tab. 1):

- The exploration and exploitation of primary energy sources.
- The conversion of primary energy sources into secondary energy in refineries and power plants.
- Transmission and distribution of fuels.
- The final consumption of fuels at refuelling stations.

Les émissions liées à l'utilisation d'énergie incluent les émissions de CO<sub>2</sub>, de méthane CH<sub>4</sub>, de protoxyde d'azote N<sub>2</sub>O, d'oxydes d'azote (NO<sub>x</sub>), de monoxyde de carbone (CO) et de Composés Organiques Volatils Non-Méthaniques (COVNM). Elles comprennent également les émissions de dioxyde de soufre (SO<sub>2</sub>) (Tab. 1).

The energy sector emitted 47,890 GWP CO<sub>2</sub>e in 2010 and 55,249 GWP CO<sub>2</sub>e in 2014, an increase of 15% between the two years. Total emissions from the energy sector remain dominated by CO<sub>2</sub> (>97%) followed by CH<sub>4</sub> and N<sub>2</sub>O (about 1% each).

Emissions from energy use include emissions from combustion and so-called fugitive emissions. Combustion is therefore the main source of emissions representing 99.6% of total emissions for the years 2010 and 2014.

### 3 Methodology and materials

The methodology involves the following main steps:

- Conducting a literature review on the role of renewable energy in promoting environmental protection.
- Providing an overview of greenhouse gas emissions in Morocco.
- Examining the environmental impact of the NOOR 1 Concentrated Solar Power (CSP) project on the site area.
- Assessing the study area's exposure.
- Collecting data and presenting analysis tools.
- Analyzing the results.

### 4 Field study: NOOR 1 (Concentrated Solar Power)-Southern Morocco region

The development of the NOOR 1 project in the Atlas Mountains of southern Morocco is set in a long-standing context of complicated vulnerability, characterised by social pressure, economic marginalisation and, above all, environmental deterioration. Overall, the implementation of NOOR 1 is seen as an important catalyst for development and increased regional prosperity.

Coordinated by the Moroccan Agency for Solar Energy (MASEN), NOOR 1 is a 160 MW CSP plant equipped with a parabolic mirror array (Fig. 1), a 3-hour salt thermal storage system, and a water-cooled steam circuit.

Furthermore, the potential environmental impact of a solar project is strongly and directly related to the technology used. In the case of the NOOR 1 solar project the technology adopted is CSP.

#### 4.1 NOOR 1's CSP technology: advantages and disadvantages

In CSP technology, the sun's rays are concentrated by mirrors at a focus where a heat transfer fluid circulates. The captured heat produces steam, which is then converted into electricity by a turbine generator.



**Fig. 1.** NOOR 1 (CSP) installation.

#### \*Advantages of CSP

Concentrated Solar Power (CSP) technology has several advantages over other forms of renewable energy:

- High efficiency: CSP technology uses mirrors to concentrate sunlight onto a receiver, which then converts the sunlight into thermal energy. This allows for a high level of energy conversion efficiency, typically between 20% and 40%.
- Energy storage: CSP systems can store the thermal energy they produce in the form of hot molten salt or other thermal storage systems. This allows for the generation of electricity even when the sun is not shining, providing a reliable source of energy.
- Flexibility: CSP systems can be configured to provide both electricity and heat, making them suitable for a wide range of applications, including power generation, water desalination, and industrial process heat.
- Low carbon footprint: CSP systems do not emit greenhouse gases during operation and the energy produced is clean and sustainable.
- Technology maturity: CSP technology is well-established and has been in use for decades. It has been proven to be reliable and cost-effective.
- Grid integration: CSP plants can be connected to the power grid, allowing for the integration of large amounts of renewable energy into the power system.
- Dispatchability: CSP plants can be dispatched to generate electricity when it is needed, providing a reliable source of energy for the grid.
- Power generation during peak hours: CSP plants can provide power during peak hours, when electricity demand is high and other forms of renewable energy may not be available.
- Scalability: CSP plants can be scaled up or down to meet changing energy demand, making them suitable for a wide range of applications.
- Durability: CSP systems are durable and can last for decades with proper maintenance.
- Remote area: CSP systems can be installed in remote areas where other forms of energy are not easily accessible.
- High capital costs: CSP plants are capital-intensive and require large amounts of initial investment.
- Land use: CSP systems require a large amount of land, which can be a limitation in areas with limited land resources.
- Weather dependence: CSP systems depend on clear weather conditions to generate electricity. Cloudy or overcast days can reduce the output of a CSP plant.
- Sensitivity to dust and sand: CSP systems are sensitive to dust and sand accumulation on mirrors, which can reduce the efficiency of the system.
- Limited availability: CSP technology is not widely available, and it can be challenging to find equipment and skilled labor for the installation and maintenance of CSP plants.
- Transportation and assembly: CSP systems require the transportation of large mirrors and equipment, which can be difficult and costly in remote areas.
- Energy loss: CSP systems are sensitive to energy loss during transmission and distribution.
- Maintenance: CSP systems require regular maintenance to ensure that the mirrors and receivers are clean and in good condition.
- Water consumption: CSP systems require water for cooling, which can be a problem in regions with water scarcity.

There are also some disadvantages associated with using Concentrated Solar Power (CSP) technology in conjunction with fossil fuels:

- Increased complexity: Using CSP technology in conjunction with fossil fuels increases the complexity of the system, making it more difficult to operate and maintain.
- High capital costs: The additional cost of incorporating CSP technology into a fossil fuel power plant can be significant.
- Emissions: While CSP can reduce emissions, it doesn't eliminate them completely and the emissions from fossil fuel power plants will still exist.
- Dependence on fossil fuels: CSP systems that are used in conjunction with fossil fuels, still depend on the availability of fossil fuels. In case of scarcity or high prices, the CSP system may not be able to operate at full capacity.
- Cost of integration: Integrating CSP technology into a fossil fuel power plant can be costly, both in terms of the equipment and the infrastructure required.

#### \* Disadvantages of CSP

It is important to recognize that, like all technologies, CSP technology also presents certain constraints and obstacles. These may include:

**Table 2.** Environmental impact indicators used in the qualitative analysis [30].

|                      | Indicator                                     | objective                                                                                                                                    |
|----------------------|-----------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| Environmental impact | Species at risk                               | Water and energy consumption at a sustainable level.                                                                                         |
|                      | Ensure local/regional water and energy supply | Stabilisation of GHG concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system. |
|                      | GHG emissions                                 | Stopping emissions of harmful substances into the atmosphere.                                                                                |
|                      | Heavy metal emissions to air and water        | Stopping emissions of heavy metals into the air and water.                                                                                   |
|                      | Output of waste                               | Level of wastes in accordance with sustainable management.                                                                                   |
|                      | Biodiversity                                  |                                                                                                                                              |
|                      | Geology and soil                              |                                                                                                                                              |
|                      | Pollution                                     |                                                                                                                                              |
|                      | Noise and vibration                           |                                                                                                                                              |
|                      | Climate change                                |                                                                                                                                              |

- Environmental impact: CSP systems that are used in conjunction with fossil fuel power plants may still have negative environmental impacts, such as air and water pollution from the burning of fossil fuels.
- High levelized cost of energy (LCOE): CSP systems tend to have a higher levelized cost of energy (LCOE) compared to other forms of renewable energy, such as solar PV.
- High temperature and heat loss: CSP systems are sensitive to high temperature and heat loss, which can reduce the overall efficiency of the system.

It is important to consider the potential disadvantages of CSP technology when evaluating its suitability for a specific project. However, with proper planning and design, many of these disadvantages can be mitigated and the advantages of CSP technology can be fully realized.

#### 4.2 Techniques and methods of data collected and content analysis

- Main indicators used: A list of the various impact indicators used in the qualitative analysis is drawn from the DPSIR « Driving Forces; Pressure; State; Impact; Response » model and adapted to our case study according to the following (Tab. 2).

This list of indicators helped us to identify the different questions asked during the interviews and the literature review.

The interview is our main source of data collection. Semi-directive interviews were conducted with several profiles that have a direct or indirect involvement with NOOR 1. The data collected comes from information obtained during the face-to-face exchange with different respondents (semi-directive interviews), who were asked about the installation of NOOR 1 in the South region, its operating mechanism, its technology, and its local and regional environmental consequences.

The codification and analysis approach adopted is based entirely on Nvivo 12 software (Fig. 2).

The encoding by source (Fig. 3) allowed the gathering of all information collected from the semi-directive interviews and documentation.

The collected information covers all the factors (at different percentages of coverage) that can explain the environmental impact of NOOR 1 on the southern region.

## 5 Results and discussions

To classify and evaluate the significance of the environmental impact of NOOR 1 on the southern region, we used the following reading grids:

### 5.1 Impact significance

Based on the processing of data collected through interviews (verbatim) and documentation in Nvivo 12, we were able to classify each impact in accordance with its order of importance. Five levels of impact significance were therefore adopted: “Strong”, “Substantial”, “Moderate”, “Trivial” and “no impact” as follows (Fig. 4).

### 5.2 Status and type of impact

There are two categories of impact status: either an effect on the chosen indicator is tangible, real and concrete: in this case the impact is classified as “Observed Impact”, or we anticipate results and effects that will be observed in the future if we use current data and achievements, in which case the impact will be classified as “Anticipated Impact”. Also, we have considered two kinds of impact: “positive” symbolized by the (+) sign and “negative” symbolized by the (–) sign:

| Status             | Type            |   |
|--------------------|-----------------|---|
| Observed impact    | Positive impact | + |
| Anticipated impact | Negative impact | – |

|    |                                                          |
|----|----------------------------------------------------------|
| 1. | Enviromental impact study                                |
| 1. | Noor 1 as a project - Territorial choice and indicators  |
| 2. | Masen as stakeholder                                     |
| 3. | Developers & promoters as stakeholders                   |
| 4. | Regional population as an actor                          |
| 5. | Project technology (CSP) and environmental externalities |
| 1. | Positive externalities                                   |
| 2. | Negative externalities                                   |
| 6. | Enviromental impact of Noor 1                            |
| 1. | Positive impact                                          |
| 2. | Negative impact                                          |
| 7. | Enviromental impact of renewable energy                  |

Fig. 2. Node created under Nvivo 12 to handle the verbatims of semi-directive interviews.

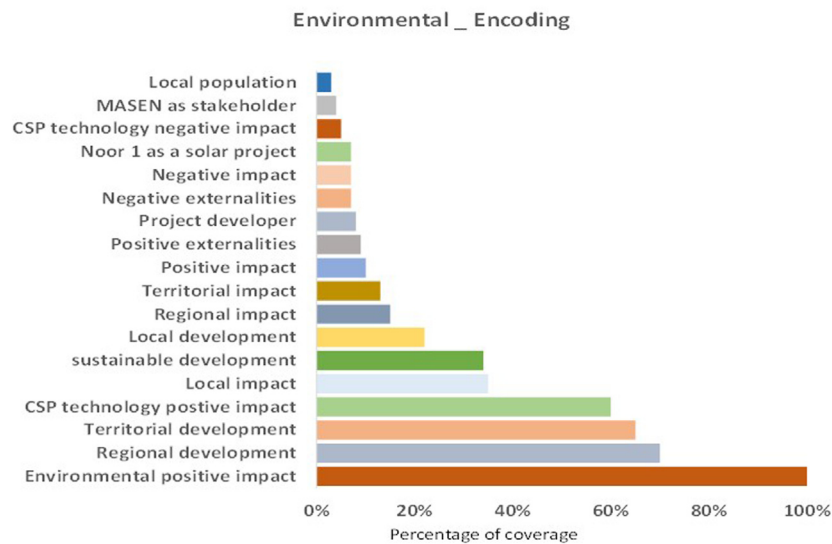


Fig. 3. Encoding by source \_ Environmental dimension.

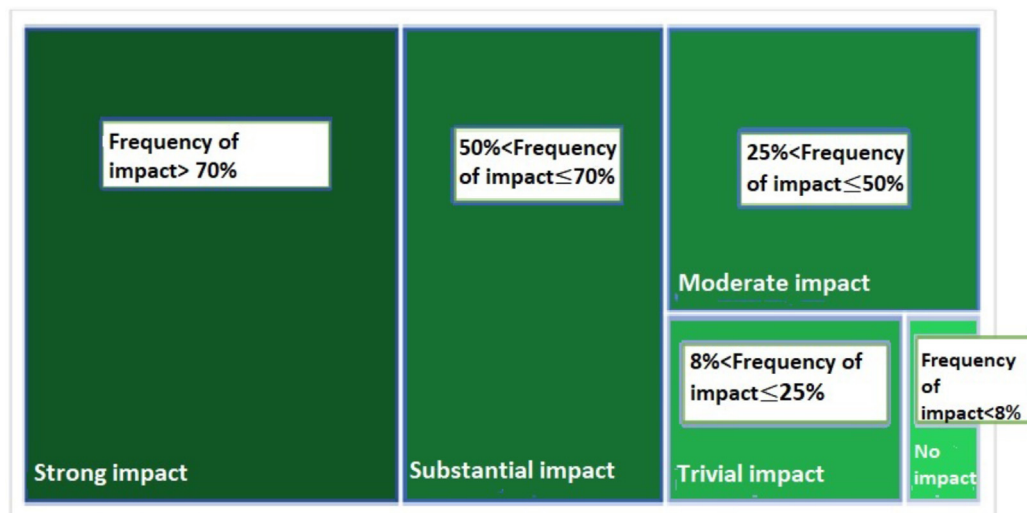


Fig. 4. Impact significance reading grid.

### 5.3 Results analysis (Tab. 3)

Although a solar project NOOR 1 utilizing Concentrated Solar Power (CSP) technology has the ability to generate clean and sustainable energy, it may also have adverse effects on air quality, water resources, biodiversity, and soil quality. To alleviate these negative impacts, certain mitigation measures should be implemented.

#### \*Air Quality

- Use advanced technologies to reduce emissions from CSP plants, such as the use of selective catalytic reduction (SCR) systems, low-NO<sub>x</sub> burners, and electrostatic precipitators.
  - Minimize dust and particulate matter emissions during construction by implementing best management practices, such as using water trucks to dampen dust, and covering stockpiles of materials.
  - Conduct air quality monitoring and modeling to assess the impacts of CSP plants on air quality.

#### \* Water Resources

- Use dry-cooling systems instead of wet-cooling systems to minimize water use and reduce the potential for water pollution.
- Implement water conservation measures such as using recycled water, implementing water-efficient practices, and reducing evaporation losses from storage ponds.
- Conduct water quality monitoring and modeling to assess the impacts of CSP plants on water resources.

#### \* Biodiversity

- Conduct ecological surveys to identify and protect sensitive habitats and species in the area of CSP plants.
- Use low-impact construction techniques to minimize disturbance to wildlife habitats.
- Implement habitat restoration programs to enhance biodiversity in areas impacted by CSP plants.

#### \* Soil Quality

- Use best management practices during construction to minimize soil erosion and sedimentation, such as implementing erosion and sediment control measures and using vegetative cover.
- Implement soil conservation practices, such as reducing tillage, using cover crops, and reducing the use of pesticides and fertilizers.
- Conduct soil quality monitoring and modeling to assess the impacts of CSP plants on soil quality.
- Overall, it is important to consider the potential negative impacts of CSP technology on the environment and to implement mitigation measures to reduce these impacts. By implementing best practices and technologies, CSP plants can minimize their environmental footprint and contribute to a more sustainable energy future.

## 6 Conclusion

Apart from the NOOR 1 project, Africa is currently experiencing a surge in solar projects, ranging from community-based small-scale initiatives to large-scale utility projects. For instance, the Benban Solar Park in Egypt is among the world's largest solar parks, located in the Aswan Governorate, with a projected capacity of 1.8 GW upon completion, comprising more than 30 distinct solar projects. Additionally, the Bokpoort Concentrated Solar Power (CSP) Project in South Africa is a 50 MW CSP initiative situated in the Northern Cape Province, utilizing parabolic trough technology to generate electricity. While each of these large-scale solar projects located in different parts of Africa has its unique characteristics and environmental impacts, they can be compared generally:

- Land Use: NOOR 1 Ouarzazate Solar project, Benban Solar Park, and Bokpoort CSP Project all require significant land use for the solar panels or mirrors. However, the land requirements of these projects are relatively small compared to other energy technologies, such as hydroelectric or fossil fuel power plants.
- Water Use: Water is an essential resource for solar projects. All three projects use wet-cooling technology that requires significant amounts of water. Wet-cooling systems can have significant impacts on local water resources, especially in arid regions.
- Greenhouse Gas Emissions: All three projects help to reduce greenhouse gas emissions by generating electricity without burning fossil fuels. However, the production and transportation of the solar panels or mirrors used in these projects can result in emissions of greenhouse gases.
- Impact on Local Habitats: The construction and operation of large-scale solar projects can impact local habitats and ecosystems. The NOOR 1 solar project was built in a desert area, which has already been significantly impacted by human activities. The Benban Solar Park is located on farmland, and its construction has displaced some local farmers. The Bokpoort CSP Project is situated in a semi-arid area, which is home to a diverse range of plant and animal species.

To sum up, while the NOOR 1 Solar project, Benban Solar Park, and Bokpoort CSP Project may cause certain environmental impacts, they offer considerable advantages in reducing greenhouse gas emissions, improving energy accessibility, and minimizing reliance on fossil fuels. The precise environmental effects of each project are contingent on factors like the location, technology, and local ecosystems and necessitate a case-by-case evaluation.

In general, renewable energy (RE) projects can help fulfill the surging demand for energy while substituting the utilization of fossil fuels. The investigation indicates that implementing an RE project is liable to promote sustainable development at the regional level. Moreover, the study enhances comprehension of the intricate relationship between environmental protection and large-scale RE installations, even though it concentrates on CSP technology. The approach and findings are not necessarily restricted to CSP and could be adapted for

**Table 3.** Synthesis of the environmental impact of NOOR 1(CSP) on the southern region of Morocco.

| Environmental impact                                 | Status      | Type | Initial state in the region | Impact signifiacnce                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|------------------------------------------------------|-------------|------|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Protection of the natural resources and biodiversity | Observed    | +    | Strong                      | <p>Carry out compensatory measures such as:</p> <p>Minimising storage areas and construction routes on the project worksite.</p> <p>Maintain existing vegetation as much as possible.</p> <p>Avoid the use of pesticides as much as possible.</p> <p>Avoid unnecessary cutting of vegetation, especially in areas around river</p> <p>Make the revegetation process easier in areas where construction is difficult.</p> <p>Ensure that waste from the site is disposed of and workers are made aware of the requirement not to hunt or harm local wildlife.</p> <p>Only native vegetation is planted on the site in relation to landscaped areas.</p> <p>Establish procedures for any species found on the construction site for notification, identification and potential relocation.</p> <p>Comply with environmental protection standards and regulations</p> <p>Defend undeveloped interstitial spaces within the project site, resulting in the regeneration of the flora and fauna of these spaces.</p> <p>Minimise the risk of disturbance to wildlife during the works.</p> <p>Installation of an evaporation basin to avoid discharge into the natural environment</p> <p>No impact on the drinking water supply</p> |
| Deteriorated security of water supply                | Anticipated | –    | Substantial                 | <p>Groundwater</p> <p>Very high-water consumption (watering of runways, sanitary facilities, frequent cleaning of curved mirrors and wet cooling (6 Mm<sup>3</sup>/year).</p> <p>Risk of conflict of use with irrigation.</p> <p>Risk of contamination of rainwater due to the use of synthetic oil and fuel oil.</p> <p>Underground water</p> <p>No recharge required, no underground water at the project site (very little, vulnerable underground water below in the valley)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| GHG emission reduction                               | Observed    | +    | Strong                      | <p>Compliance with air pollution control regulations and exhaust emission standards for the operation's machinery.</p> <p>Saving millions of tons of CO<sub>2</sub> per year</p> <p>Regarding the impact on the climate, no land clearing was required during the implementation of the NOOR 1 solar project.</p> <p>Improved air quality in the region.</p> <p>Production of clean energy.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |

**Table 3.** (continued).

| Environmental impact                               | Status      | Type | Initial state in the region | Impact significance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|----------------------------------------------------|-------------|------|-----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Emissions from CSP technology and associated risks | Anticipated | –    | Trivial                     | <p>Major source of risk due to the presence of fossil fuel.</p> <p>Risk related to the turbine: there is a risk of fire and explosion due to the pressurised and hot (400°C) operation of the turbine and the use of gas or oil, in small quantities.</p> <p>Risk of atmospheric release of water vapour and some gases due to the additional use of oil, needed for the correct operation of the turbine.</p> <p>Risks of pollution related to the presence of oil as a heat transfer fluid (leaks in the pipes) which may indirectly affect the rivers with a high heritage value downstream of the project site, and the lake of the “Mansour Ed Dahbi” dam.</p> <p>Exhaust gases and dust from vehicles and discharges linked to the supply of fossil fuels.</p> <p>Risk related to thermal storage: storage is done using molten salts which are a mixture of 60% sodium nitrate which is harmful if ingested and promotes the ignition of combustible materials and 40% potassium nitrate (which promotes the ignition of combustible materials).</p> |
| Efficient waste management                         | Observed    | +    | Substantial                 | <p>The various categories of waste are disposed of by specialised companies.</p> <p>Domestic waste is disposed of in dump sites.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Weathering of geology and soil                     | Observed    | –    | Trivial                     | <p>Impact on waterproofing related to the surface works concerning the NOOR 1 technology (CSP):</p> <p>Cement for the solar panels anchoring (both horizontal (surface) and vertical (depth in the ground or height above ground) requirements.</p> <p>Installation of technical buildings and offices.</p> <p>Installation of electrical cables.</p> <p>Installation of thermal storage tanks (i.e., maximum total of 434,000 m<sup>2</sup>).</p> <p>Compaction caused by:</p> <p>The movement of work vehicles.</p> <p>The installation of various equipment.</p> <p>Movement of personnel during construction and during exploitation.</p> <p>Erosion</p> <p>The soil was already bare, the project has very little impact on erosion phenomena, which are already significant in the region.</p> <p>The presence of the panels may lead to a modification of the flow of rainwater.</p>                                                                                                                                                                 |

**Table 3.** (continued).

| Environmental impact                                               | Status      | Type | Initial state in the region | Impact signifiacne                                                                                                                                                                                                                                                                                                                                                                                          |
|--------------------------------------------------------------------|-------------|------|-----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Soil pollution control                                             | Observed    | +    | Moderate                    | The cleaning process and the cooling of the mirrors generate almost no waste.<br>Only 2% to 3% of the water consumption is rejected.<br>Most of the water consumed is evaporated during the process.<br>No detergent is used.<br>The re-use of rejected water after cooling, in a closed-circuit installation is provided for.                                                                              |
| Noise and vibration                                                | Observed    | –    | Moderate                    | During the construction phase, noise pollution is caused by the traffic generated by the supply of materials and the installation of equipment.<br>In the operation phase, for NOOR 1 (CSP), the main source of noise is generated by the construction of the operation buildings housing the turbine and by the significant vehicle traffic, due to the high number of people working on the project site. |
| Fighting global warming                                            | Anticipated | +    | strong                      | Financial benefits from CO <sub>2</sub> savings.<br>GHG reduction: The GHG emissions that will be avoided by NOOR 1 are 2.9 million tons of CO <sub>2</sub> over a 10 years period, or 240 thousand tons of CO <sub>2</sub> per year (6 million tons of CO <sub>2</sub> over 25 years).<br>Solar thermodynamic energy does not directly produce waste or GHGs.                                              |
| Preservation of the environment at the end of the operating period | Anticipated | +    | Substantial                 | Restoration at the end of exploitation:<br>Fully recyclable collectors<br>Dismantling of operational buildings<br>Maintenance of a waterproof surface if not all concrete slabs are removed                                                                                                                                                                                                                 |

other large-scale RE or infrastructure projects in different regions with specific adjustments to the project sites and technologies.

An assessment of the potential environmental impacts of the NOOR 1 solar project is conducted through an environmental impact study. This study evaluates the project's impact on air and water quality, biodiversity, and land use, as well as its effects on climate change and its potential to reduce greenhouse gas emissions. The study employs qualitative analysis as a method and Nvivo 12 software for assessment to determine the significance of the impact. Additionally, the study provides recommendations for mitigating any negative impacts and monitoring the project's ongoing environmental performance. It is crucial to note that the actual environmental impact study's results and findings may differ based on the methodology and criteria used. Various methods, such as

field surveys, laboratory experiments, modeling, or a combination of methods, are employed in different studies to assess the impacts, and the criteria used to evaluate the impacts, such as thresholds for determining significant impacts, may also differ.

Furthermore, it is essential to recognize that the study's results and findings should be continuously updated and monitored as the project progresses and evolves. This will enable any negative impacts to be identified and addressed promptly, and the project to continue to operate in an environmentally responsible manner.

Looking ahead to future research, it would be beneficial to conduct a study that evaluates the impact of dust on the performance of CSP technology in the Moroccan desert region and develops more effective cleaning and maintenance strategies to improve the project's performance and longevity. Additionally, it would be valuable to conduct a

study that assesses the social and economic impact of the project on the local community, ensuring that the project benefits those living in the region.

Furthermore, the environmental impact study of the NOOR 1 solar project should also consider the potential impacts on wildlife and their habitats, including effects on migratory patterns or critical habitats for endangered species. It should also include a detailed assessment of the potential impacts on soil and soil health, including effects on erosion or nutrient cycling, as well as the potential impact on local water resources, including the potential for water scarcity and changes in water quality.

Another crucial perspective to consider is conducting a life-cycle assessment of the project to identify environmental hot spots and opportunities for improvement throughout the project's construction, operation, maintenance, and decommissioning. Additionally, it would be beneficial to evaluate the potential for the project to promote local economic development, including job creation, income generation, and poverty reduction.

Finally, a study that assesses the integration of the project with the local energy grid, including the potential for energy storage and load balancing, as well as the integration of renewable energy sources with conventional power generation, would be valuable.

## Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

## Authors contributions

A. Laaroussi, O. Laaroussi, and A. Bouayad conceived and designed the study. A. Laaroussi, O. Laaroussi wrote the paper. A. Laaroussi reviewed and edited the manuscript.

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